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AN ARBITRARY GRID CFD ALGORITHM FOR CONFIGURATION AERODYNAMICS ANALYSIS

Vol. 2. FEMNAS User Guide

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FOREWARD

This report documents the user input and output data requirements for the FEMNAS finite element Navier-Stokes code for real-gas simulations of external aerodynamics flowfields. This code was developed for the configuration aerodynamics branch of NASA Ames Research Center, under Small Business Innovation Research (SBIR) Phase II contract NAS2-12568 by Computational Mechanics Corp. (COMCO). The project Technical Monitor for this effort was Dr. Larry Erickson of NASA Ames.

This report is in two volumes. Volume I contains the theory for the derived finite element algorithm and describes the test cases used to validate the computer program described in the volume II user guide.

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1.0 INTRODUCTION

The Finite Element NASA (FEMNAS) computer program system is designed to provide an accurate tool for analysis of compressible airflow over modern aircraft configurations at subsonic, transonic and supersonic speeds and high altitude. FEMNAS is designed for three-dimensional analysis, but due to limitations in the factored algorithm procedure used, useful calculation is limited to 3D axisymmetric and two-dimensional aerodynamic shapes.

This user guide describes the procedures for data preparation and execution of the FEMNAS program system for solution evolution. The remainder of this section deals with the procedures for program execution and analysis. The following sections deal with specific data files required for execution and the contents of output files generated by the code.

1.1 PROGRAM ENVIRONMENT

The FEMNAS code was developed in a workstation environment and has been made operational on the AMES Cray 2 computer under the UNICOS operating system (c-shell). This makes FEMNAS readily available through dial-up modem access or via internet through the Telnet and FTP commands for authorized users anywhere in the world.

1.2 USING FEMNAS

FEMNAS is executed in batch mode and operates on prepared data files. Data file preparation is accomplished through a combination of special interactive programs and a text editor. Once the input files are completed, execution is accomplished via the FEMNS command as follows:

```
% FEMNS                 interactive run
% FEMNS &               background run, screen file to the terminal
% FEMNS > filename &    background run, screen file to filename
```

These are standard unix procedures. The first is usually for short runs as it denies access to the keyboard during execution but can be easily terminated with a "ctl-c" command. The second method allows use of the keyboard during execution but sends screenfile data to the screen so that run progress can be tracked while execution continues. The third method permits execution in the background and writes the screenfile to a specified file. This method is most useful for long runs where the user may choose to disconnect and return later to view the output.

2.0 FEMNAS INPUT DATA

The FEMNAS program executes using data from a series of files (ifile.xx) which contain specific problem data such as finite element grid, initial conditions, boundary conditions, time-stepping and convergence criteria, etc. The ifile.xx files are automatically generated from a user definition of the aerodynamic problem to be solved. A brief description of this ifile.xx file is given in Table 2.1.

The data preparation and FEMNAS execution procedure is outlined in Table 2.2 where the modules listed in column 1 are executed in ascending order and the files required on each module are in column 2. The third column in Table 2.2 lists the source of the input files and column 4 lists the module output files. The modules are executed in the order (1)-(8) for a complete FEMNAS solution to be evolved.

User data requirements are noted in column 3 of Table 2.2. these include an interactive Q/A description of the geometric shape and grid requirements for module 1 and description of the generated grid size for module 4 (MDATA.in). The data for these files is described in detail in sections 4.0. The balance of this section contains a description of each execution module and its data, followed by instructions for restart in section 2.3.

2.1 Grid Generation

Execution begins by executing a user-supplied interactive program which fills the 'body' file with a description of the problem flow domain. The MKBLUNT and MKARAC programs supplied with FEMNAS contains dialogue to set up axisymmetric blunt-body flows at supersonic speeds.

The next step is to sequentially execute the bgrid and ref modules to generate the cdata.m file. At this point graphical review of the generated finite element grid can be made by executing the gshowex module. An unsatisfactory grid can be changed by editing the 'body' and MDATA.in files, making an appropriate adjustment to the grid size or attraction factors and re-executing modules 2 and 3.

The BGRID module generates a macro grid file (MACRO.in) which contains a coarse grid description of the flow domain that can be automatically refined with grid attraction control via a few parameters (see section 3). The bgrid module also generates the first few input files required for the FEMNAS module (ifile. 59, .60, .62, .82).

The ref module refines the macro-grid coordinates under grid attraction control and interpolates the macro defined flow variables at the refined grid points. These are stored in the cdata.in file. The refined grid can be visually inspected by executing the gshowex module immediately after the ref module.

Table 2.1

FEMNAS Program Input File Descriptions

File Name	Description
ifile.59	contains the numerical dissipation (beta) parameters (ref. eqn. No. 77)
ifile.60	contains the number of columns and rows, number of elements, nodes, boundary nodes and number of nodes per element (four).
ifile.61	contains the initial condition distributions
ifile.62	contains the finite element nodal connection array and the boundary node vector array.
ifile.63	contains reference values of length, velocity, Reynolds number (Re) and pressure (Pr).
ifile.64	contains the x and r coordinates of the nodes.
ifile.65	contains the initial outlet pressures.
ifile.66	contains the time integration parameters.
ifile.67	contains the current time, delta time and time-step variation parameters.
ifile.68	contains information about each of the nodes such as boundary condition(s) applied (node codes) and number of variables per node.
ifile.69	
ifile.82	sfill temporary input file.

Table 2.2

FEMNAS PreProcessor and Program Components

EXECUTION MODULES	INPUT FILES	FROM	OUTPUT FILES
(1) mkblunt		keyboard (user)	body
(2) bgrid	body	mk...	ifile.59 ifile.60 ifile.62 ifile.82 macro.in
(3a) ref	macro.in mdata.in case.count jobfil	bgrid user default default	cdata.in three.d
(3b) gshowex	three.d	ref	display FE grid
(4) icplt	cdata.in mdata.in body	ref user bgrid	arrow.scale arrow.in ifile.61 ifile.64
(5) arrow	arrow.scale arrow.in	icplt icplt	three.d
(6) gshowex	three.d	arrow	display initial velocities
(7) sfill (sfill2)	ifile.60 ifile.61 ifile.62 ifile.64 ifile.82	bgrid icplt bgrid icplt bgrid	ifile.63 ifile.65 ifile.66 ifile.67 ifile.68 ifile.69
(8) femns	ifile.59 ifile.60 ifile.61 ifile.62 ifile.63 ifile.64 ifile.65 ifile.66 ifile.67 ifile.68 ifile.69	bgrid bgrid icplt bgrid sfill icplt sfill sfill sfill sfill sfill	ifile.70 ifile.71 ifile.72 ifile.92
(9) prtplt	ifile.92	femnas	name.prt
(10) comprt	name.prt	prtplt	three.d
(11) arrow	three.d	comprt	three.d
prejr			fort.xx
(12) gshowex	three.d	comprt, arrow	screen
jrex(contour)	three.d	prejr	screen

2.2 Initial and Boundary Conditions

When the grid is satisfactory, module 4 can be executed to generate an initial flowfield. The flowfield resides in files, ifile.61, .64 and can be visually inspected by sequentially executing modules 5 and 6. Note that file three.d is the graphics file. The grid from module 3 will be overwritten and should be copied to another file before this step if it is to be preserved.

The rest of the FEMNAS files are filled via an interactive program sfill2. The sfill2 program has five options and typical Q/A for each are given in section 4.

Reference Conditions

The first option (reference conditions) allows for changing the flight conditions by specifying temperature and density. Other state values are calculated and displayed as illustrated in Figure 2.1. The non-dimensional Reynolds and Prandtl and reference length scale are used to condition the equations as noted in the theory manual (eqn. 9).

Time Integration Parameters

The time integration options in Figure 2.1 refer to methods in the theoretical manual as follows:

Implicit Backward Euler (Newton)	, equations 70
Implicit Runga Kutta	, equations 67

Time-stepping Parameters

The time-step variables are self-explanatory except for the DT-variation parameter which is the step-size increment/decrement parameters. Large numbers can be tolerated for some problems depending on convergence and stability; experience is the best guide. If executions of FEMNAS show a steady increase in step-size as the solution proceeds, and the solution is smooth, a higher value may be tolerated. If, however, the step-size alternates between stepping up and stepping down and/or the solution field becomes wavey, the value of the DT-variation parameter should be reduced for subsequent runs.

Artificial Dissipation Parameters

The artificial dissipation parameters are useful for controlling the stability of advection dominant problems (see section 4G of the Theory Manual). The beta coefficients control potential instabilities for each dependent variable (ρ, M1, M2, E). Values of .3 to .4 are typical for inviscid flows. These factors are automatically reduced to zero for highly viscous regions of the flowfield such as for wall boundary layers.

```
DO YOU WISH TO SET UP REFERENCE CONDITION FILES ?
1<< YES
2<<  NO
          1

ENTER THE REFERENCE-FREESTREAM MACH NUMBER
2.

PLEASE ENTER THE PROBLEM REYNOLDS NUMBER
  700000.0000
PLEASE ENTER THE PROBLEM PRANDTL NUMBER
 0.7200000286
PLEASE ENTER REFERENCE LENGTH (METERS)
 0.1269999985E-01

 THE FOLLOWING INPUT IS REQUIRED IN SI UNITS

PLEASE ENTER FREESTREAM      DENSITY (GRAMS/CM**3)
 0.3799999878E-01
PLEASE ENTER FREESTREAM TEMPERATURE (DEGREES KELVIN)
  200.0000000

 FREESTREAM PRESSURE    =   2181.199951      NEWTON/CM**2
 FREESTREAM TEMPERATURE =   200.0000000      DEGREES KELVIN
 FREESTREAM DENSITY     =  0.3799999878E-01  GRAMS /CM**3

STAGNATION PRESSURE   =   17066.68555      NEWTON/CM**2
STAGNATION TEMPERATURE=   360.0000000      DEGREES KELVIN
STAGNATION DENSITY    =  0.1651827842      GRAMS /CM**3

 FREESTREAM VELOCITY=   566.9567871      METERS/SEC.

NON-DIMENSIONAL REFERENCE
STAGNATION AND FREESTREAM STATES

STAGNATION PRESSURE   1.397222877      NEWTON/CM**2
FREESTREAM PRESSURE  0.1785714328      NEWTON/CM**2

STAGNATION DENSITY    4.346915722       GRAMS/CM**3
FREESTREAM DENSITY    1.000000000       GRAMS/CM**3

STAGNATION ENERGY     3.493057251      JOULES
FREESTREAM ENERGY    0.9464285970      JOULES

FREESTREAM VELOCITY   1.000000000       NON-DIMENSIONAL
THE PROBLEM-PARAMETER  FILE HAS BEEN
CREATED
THE REFERENCE-CONDITION FILES HAVE BEEN
CREATED
```

Figure 2.1   Dialogue for SF1112 module

```
DO YOU WISH TO SET UP TIME-INTEGRATION
 ALGORITHM PARAMETERS ?
1<< YES
2<<  NO
          1

TYPE OF INTEGRATION ALGORITHM ?
1=IMPLICIT BACKWARD EULER
2=IMPLICIT RUNGE-KUTTA
          1

ENTER NUMBER OF NEWTON ITERATIONS (>=2)
          4
THE TIME INTEGRATION ALGORITHM PARAMETER
FILE HAS BEEN CREATED




DO YOU WISH TO SET UP TIME STEP
 VARIATION PARAMETERS ?
1<< YES
2<<  NO
          1
 THE FOLLOWING INPUT IS REQUIRED
 IN NON-DIMENSIONAL FORM

INITIAL TIME ?
 0.0000000000E+00
TIME MAX ?
  10.00000000
TOTAL NUMBER OF STEPS ?
        100
MINIMUM TIME STEP ? (< INITIAL DT !)
 0.9999999747E-04
INITIAL TIME STEP ?
 0.1000000047E-02
MAXIMUM TIME STEP ?
 0.1000000015
USER DEFINED ZERO ?
 0.9999999747E-04
DT-VARIATION PARAMETER (0.0< PAR <=1.0)
 0.3000000119
THE TIME STEP VARIATION PARAMETER FILE
 HAS BEEN CREATED



DO YOU WISH TO SET UP DISSIPATION DATA  FILE ?
1 << YES
2 << NO
          2
```

Figure 2.1   Dialogue for SF1112 module, concluded

Boundary Conditions

The boundary condition information is the final sequence and is input by boundary segments. For a representative problem, eight boundary condition segments are considered: four boundary corners, a wall boundary, an inlet, an outlet and a symmetry line.

The boundary condition information is somewhat complicated, requiring further explanation. The flow domain is subdivided into a structured finite element mesh. Figure 2.1 illustrates the method on a coarse (5 rows x 5 cols.) element grid (6 rows x 6 cols. nodal grid). The gridpoints are numbered as illustrated at the element vertices. The finite elements have numbers associated with their (row, col.) pair location as illustrated below. Each finite element has a local node numbering sequence which is counter-clockwise beginning at the node closest to the origin (node 1). For example, the local node numbering for element (3,2) is 9 15 16 10 and these node numbers correspond to local node numbers 1, 2, 3, 4.

Boundary data are entered in counter-clockwise order beginning at node 1. The data is entered for the nodes associated with a boundary segment being input. Boundary segments can contain from one to several nodes. The only limitation is that all nodes of a segment have the same boundary condition. Generally, for aerodynamic flow problems, eight (8) boundary condition segments will be required, 4 corners (ie: 1, 31, 36, 6) and 4 sides.

The sfill2 interactive dialogue follows the pattern for each section of boundary input is as follows:

1. type of boundary - inflow, outflow, wall, etc.
2. type of boundary condition for each variable (rho, m_1, m_2, E)
3. left extreme node of the section
   element row,
   element column,
   element local node number (1,2,3,4)

The dialogue for boundary conditions input can be lengthy. For presentation clarity an example (see section 4.3) is presented in Appendix A.

2.3 Restart

A femnas steady state selection is marched through time to a steady state. The number of time steps for a computer run is user input under time-stepping parameters (see section 2.2). If a run is satisfactory but doesn't reach the steady state, it can be continued from the ending point by transferring output to input files and refunning femnas.

The data requirements and recommended precedures for a restart are as follows:

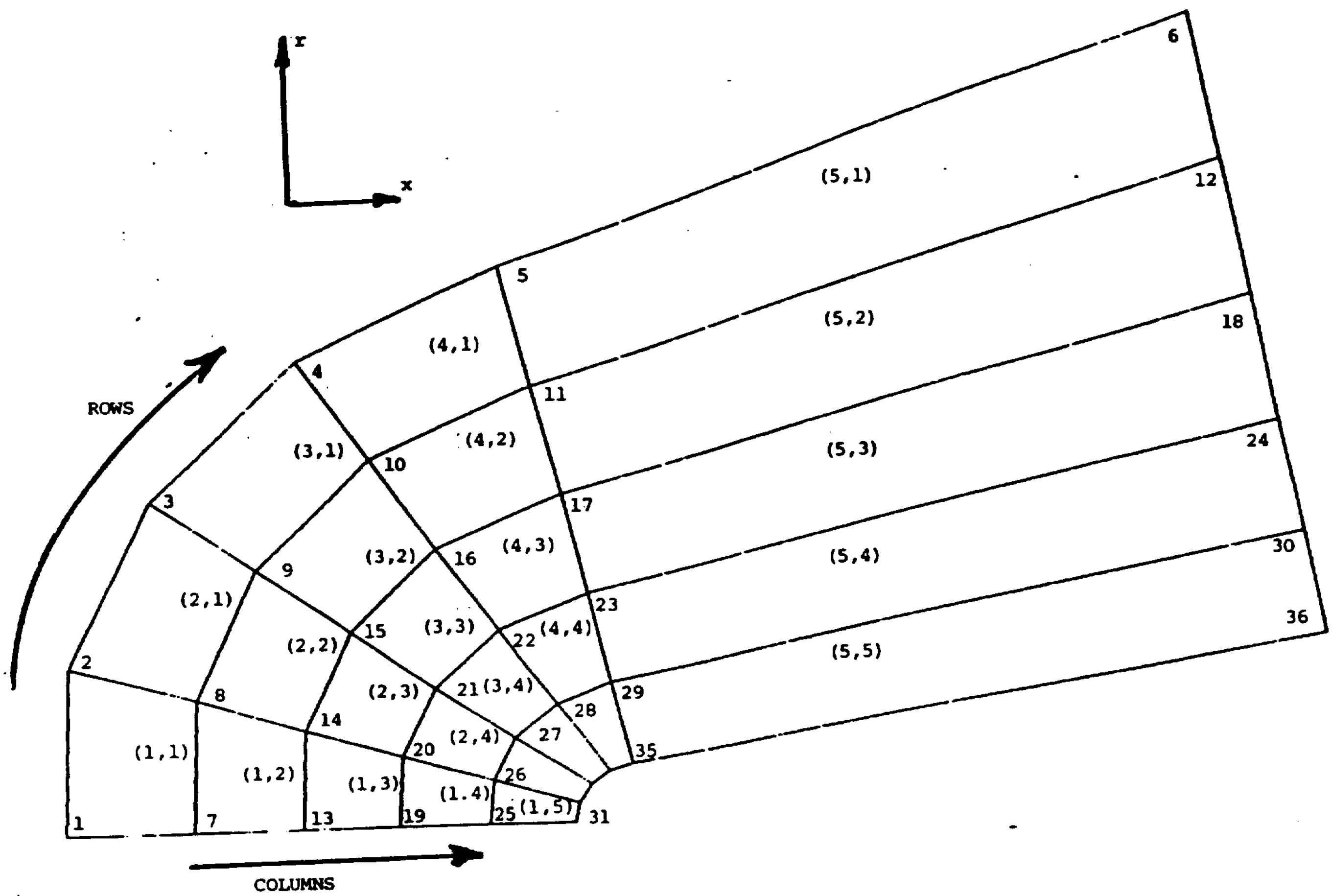


Figure 2.2 FEMNAS boundary data

1. Save all IFILE files from the previous run by copying them to another subdirectory.

2. Copy the OUTPUT file IFILE.92 to the initial condition Input file IFILE.67.

3. Copy the output file IFILE.71 to the time variables input file IFILE.61 and edit if parameter changes are required. (see section 3.1).

4. Execute the FEMNS module

3.0 FEMNAS Output and Graphics

Table 2.2 indicates that the femnas module has four output files (IFILE.70, IFILE.71, IFILE.72 and IFILE.92). This section describes the contents of these files and how to graphically display the contents.

3.1 Output Files Description

The IFILE.70 file contains time integration and stepping criteria. This file is useful for restarting a problem since it contains time and step information concurrent with the maturity of the solution variables output in IFILE.71, and is already in the appropriate input data format. The contents of IFILE.70 for a 300 step run are illustrated in Figure 3.1. The first 50 lines of the solution variables in IFILE.71 are presented in Figure 3.2.

The IFILE.72 file contains a reflection of the problem input parameters, solution performance criteria at each solution step and a geometry mapped display of the primary physical variables.

The problem input parameters print is illustrated in Figure 3.3. The print includes an accounting of the finite element grid size followed by a reflection of input and calculated reference states, stability criteria and time integration information.

The solution performance information printed at each solution step is presented for the first and last step of a 100 step run in Figure 3.4. The information consists of time-dependent scalar information such as current time, step-size, etc., and minimum values of the primary distributed variables, (1) density, (2) x-momentum, (3) y-momentum, (4) energy. Comparison of Figures 3.4a and 3.4b illustrates the solution progress after 100 steps. The model time has advanced from 0 sec. to .256 seconds for an average step-size (DT) of .00256 seconds. The Newton iteration tracker at the top indicates that at step 100 the maximum change in distributed variables (DQ) actually increased at the second iteration and the step-size was decreased to obtain a successful iteration level of .0275. The variable limiting step size is seen to be the energy, by comparing the "sup norm" value with the max DQ values.

The (MAX RES), (MAX F) and (MAX DQ) values for each primary variable correspond to the variables in the Theory manual known as the residuals (g) the Newton right side (f) and the change in dependent variable (dq) respectively. Maximum values of these components and their (x,y) coordinate location is highly useful in determining the maturity and quality of a solution.

The residuals, for example, must tend toward zero in the steady-state except at nodes where non-zero dirichlet (fixed) conditions are imposed. Since the (MAX RES) values in Figure 3.4b are about the same as for 3.4a, it is clear that the solution is far from converged to a steady-state after 100 time-steps.

```
 10000.00000              300  0.0000000000E+00
0.9999999747E-04  0.1000000015      0.3000000119      0.9999999747E-04
0.7923297882      0.2538793720E-02
0.1699367166E-01  0.1646621674      0.5183531903E-02
0.1000000047E-02  0.0000000000E+00         300
```

ifile.70 Variable Names

```
WRITE(70,*) TMAX,ISTMA,ENRGYO
WRITE(70,*) DTMIN,DTMAX,TOL,EPS
WRITE(70,*) TIME,DT
WRITE(70,*) RESS,DQMAX,DQMIP
WRITE(70,*) DTOPT,CONVR,NSTE
```

TMAX - solution time limit
ISTMA - current step number
ENRGYO -
DTMIN - minimum step size
DTMAX - maximum step size
TOL - step increment
EPS - solution convergence criteria
TIME - current time
DT - current step size
RESS -
DQMAX - maximum level step change in array dependent variable before step size is reduced
DQMIP - minimum level of step change in any dependent variable before step size is increased.
DTOPT -
CONUR -
nste - maximum number of time steps this run

Figure 3.1 Final solution time integration and stepping output useful for restarting a problem (ifile.70).

Density	M1	M2	Energy
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.000000000	1.000000000	0.0000000000E+00	0.9464300275
1.040799975	0.9607990980	0.0000000000E+00	0.9751036167
1.005042791	0.9972804785	0.0000000000E+00	0.9492920637
1.005085468	0.9972586632	0.3469768853E-04	0.9493250847
1.005237222	0.9971756935	0.6559944450E-04	0.9493912458
1.005497575	0.9970414042	0.9579509788E-04	0.9495602846
1.005879521	0.9968335629	0.1400166802E-03	0.9497662783
1.006398559	0.9965602756	0.1888383122E-03	0.9500743151
1.007063627	0.9962029457	0.2536463435E-03	0.9504504800
1.007897735	0.9957597256	0.3386329336E-03	0.9509335756
1.008913994	0.9952206016	0.4424602666E-03	0.9515210986

Figure 3.2 Final solution distributed variables useful for restarting a run (ifile.71)

```
            ************************************************
                        COMCO CODE:  FEMNAS
            ************************************************


            ***** COMPUTATIONAL DOMAIN INFORMATION *****

                  TYPE OF ELEMENT: LAGRANGE BILINEAR
                      4   NODES PER ELEMENT

                     50   ROWS    OF ELEMENTS
                     50   COLUMNS OF ELEMENTS
                   2500   ELEMENTS IN TOTAL
                   2601   NODES IN TOTAL
                    200   OF WHICH ARE BOUNDARY NODES




***** PROBLEM PARAMETERS *****

REFERENCE PRESSURE         REFERENCE DENSITY
  12214.71973                 0.3799999878E-01

REFERENCE VELOCITY         REFERENCE LENGTH
  566.9567871                 0.1269999985E-01

REYNOLDS #:    700000.0000
MACH     #:    2.000000000
PRANTL   #:   0.7200000286

SUBSONIC OUTFLOW
EXIT AVERAGE PRESSURE:     2181.199463


STABILITY PARAMETERS

ETA-1 DIRECTION:
1ST   BETA COEF.  2ND   BETA COEF. 3RD   BETA COEF.   4TH   BETA COEF
 0.4000000060       0.4000000060        0.4000000060          0.4000000060

ETA-2 DIRECTION:
1ST   BETA COEF.  2ND   BETA COEF. 3RD   BETA COEF.   4TH   BETA COEF
 0.4000000060       0.4000000060        0.4000000060          0.4000000060

***************************************************************************


***************************************************************************


***** TIME INTEGRATION ALGORITHM INFORMATION *****

BACKWARD EULER RULE

NO. OF STAGES      THETA    TOT. NO. OF UPDATES
         1   1.000000000              100

MAX. NO. OF NEWTON ITERATIONS
          4


STEADY-STATE RES TOLERANCE DT-VARIATION PARAMETER
 0.9999999747E-04                 0.3000000119

INITIAL DT      INITIAL TIME
 0.1000000047E-02  0.0000000000E+00

FINAL TIME
  10.00000000

MINIMUM DT:    0.9999999747E-04
MAXIMUM DT:    0.1000000015
***************************************************************************


***************************************************************************
```

Figure 3.3   Problem input parameters (ifile.72)

```
COMPUTATIONAL PROCESS INFORMATION

 NEWTON ITERATION #:            1       |dQ|  SUP  NORM:  0.1431447361E-01

CURRENT TIME
 0.1000000047E-02

LATEST  DT           NEXT  DT          # OF STEPS
 0.1000000047E-02       0.1500000013E-02          1


STABILITY PARAMETERS

ETA-1 DIRECTION:
1ST   BETA COEF.  2ND   BETA COEF. 3RD   BETA COEF.   4TH   BETA COEF
 0.4000000060       0.4000000060        0.4000000060        0.4000000060

ETA-2 DIRECTION:
1ST   BETA COEF.  2ND   BETA COEF. 3RD   BETA COEF.   4TH   BETA COEF
 0.4000000060       0.4000000060        0.4000000060        0.4000000060


INITIAL RHS RESIDUAL

MAX RES 1:  0.1121891942E-01  X= 0.5467771553E-02  Y= 0.1207740046E-02
MAX RES 2:  0.1699367166E-01  X= 0.8680991828E-02  Y= 0.1726260036E-01
MAX RES 3:  0.5534492084E-03  X= 0.1247081161E-01  Y= 0.2576829679E-01
MAX RES 4:  0.9607223794E-02  X= 0.5467771553E-02  Y= 0.1207740046E-02

NEWTON-ALGORITHM RESIDUAL AT LAST ITERATION

MAX  F  1:  0.1121892001E-04  X= 0.5467771553E-02  Y= 0.1207740046E-02
MAX  F  2:  0.1699367203E-04  X= 0.8680991828E-02  Y= 0.1726260036E-01
MAX  F  3:  0.5534492402E-06  X= 0.1247081161E-01  Y= 0.2576829679E-01
MAX  F  4:  0.9607224456E-05  X= 0.5467771553E-02  Y= 0.1207740046E-02

MAXIMUM CHANGE IN VARIABLES

MAX  DQ 1:  0.1080635935E-01  X= 0.1214605197E-01  Y= 0.0000000000E+00
MAX  DQ 2:  0.5619731732E-02  X= 0.1214605197E-01  Y= 0.0000000000E+00
MAX  DQ 3:  0.1475063036E-02  X= 0.1425798237E-01  Y= 0.7394530810E-02
MAX  DQ 4:  0.1431447361E-01  X= 0.1246666163E-01  Y= 0.0000000000E+00

*************************************************************************
```

Figure 3.4a Solution performance criteria, step 1 (ifile.72)

```
COMPUTATIONAL PROCESS INFORMATION

 NEWTON ITERATION #:          1      |dQ|  SUP  NORM:  0.1184156910

 NEWTON ITERATION #:          2      |dQ|  SUP  NORM:  0.4298970699

 NEWTON ITERATION #:          1      |dQ|  SUP  NORM:  0.2750948258E-01

CURRENT TIME
 0.2563513517

LATEST  DT           NEXT  DT           # OF STEPS
 0.9094622801E-03      0.1364193391E-02        100


STABILITY PARAMETERS

ETA-1 DIRECTION:
1ST   BETA COEF.   2ND   BETA COEF.  3RD   BETA COEF.   4TH   BETA COEF
 0.4000000060        0.4000000060        0.4000000060        0.4000000060

ETA-2 DIRECTION:
1ST   BETA COEF.   2ND   BETA COEF.  3RD   BETA COEF.   4TH   BETA COEF
 0.4000000060        0.4000000060        0.4000000060        0.4000000060


INITIAL RHS RESIDUAL

MAX RES 1:  0.8642795496E-02  X= 0.1084065065E-01  Y= 0.7582049584E-03
MAX RES 2:  0.4298017360E-02  X= 0.1163740177E-01  Y= 0.1667050086E-01
MAX RES 3:  0.2139408607E-02  X= 0.1258059125E-01  Y= 0.7138860412E-02
MAX RES 4:  0.1149609778E-01  X= 0.1084065065E-01  Y= 0.7582049584E-03

NEWTON-ALGORITHM RESIDUAL AT LAST ITERATION

MAX  F  1:  0.7860296137E-05  X= 0.1084065065E-01  Y= 0.7582049584E-03
MAX  F  2:  0.3908884537E-05  X= 0.1163740177E-01  Y= 0.1667050086E-01
MAX  F  3:  0.1945711347E-05  X= 0.1258059125E-01  Y= 0.7138860412E-02
MAX  F  4:  0.1045526733E-04  X= 0.1084065065E-01  Y= 0.7582049584E-03

MAXIMUM CHANGE IN VARIABLES

MAX  DQ 1:  0.8550933562E-02  X= 0.1083503105E-01  Y= 0.0000000000E+00
MAX  DQ 2:  0.1645687968E-01  X= 0.8467361331E-02  Y= 0.9511170210E-03
MAX  DQ 3:  0.2195223002E-02  X= 0.1229286194E-01  Y= 0.6468920037E-02
MAX  DQ 4:  0.2750948258E-01  X= 0.8448561653E-02  Y= 0.0000000000E+00
*************************************************************************
```

1 Density (RHO)

2 X1 Momentum (RHO*u)

3 X2 Momentum (RHO*v)

4 Energy

Figure 3.4b Solution performance criteria, step 100 (ifile.72)

The (MAX F) values are useful since they tend toward zero, each step, as the Newton algorithm converges. Values of 10^{-5} (nominal) are typical of a reasonably converged iteration. Finally the (MAX Q) values indicate the maximum change for each primary variable (Q) at the current step. This indicates which variable is controlling the solution step-size. At step 1 (Figure 3.4a) the solution is controlled by density and energy. By step 100 (Figure 3.4b) the x1-momentum is seen to begin dominating.

At the last step requested (100 in this case), the entire field for 12 variables is printed in geometric form on a 120 column width print field. The print of density is illustrated at step 100 in Figure 3.5. The print is organized to flow from left to right in sections of 120 characters and from top to bottom so that the location of each value is spacially correct as if one were viewing the model. The print shown in Figure 3.5 has some overlap because the printer is set up for 80 column fields rather than 120. The print mapping is illustrated, (Figure 3.6).

A list of the printed distributed variables is given in Figure 3.7. The first four are the primary print variables (density, x-velocity, y-velocity, and energy). The velocities are derived from the momentum and density (m= u) ; pressure is computed from the energy. The courant numbers are as described in the theoretical manual (section 5A2) and the coordinates are as input.

3.2 Graphics

Graphical presentations of the output variables listed in Figure 3.7 can be obtained by editing the IFILE.92 file and writing the coordinates and variables to be plotted to separate files. Once this is done, the PLTOUT and COMPRT programs are executed to set up a plot file for the display module GSHOWEX. This section describes the use of the PLTOUT and COMPRT modules to obtain a plot file.

The PLTOUT module reformats the data files extracted from IFILE.90 for compatibility with the COMPRT module. The interactive input for PLTOUT is illustrated in Figure 3.8. The data requirements are the grid size and the file name containing the data. The output file name is the input file name with the extent .PLT appended.

Once the essential .PLT files have been created, the COMPRT program can be executed to obtain various types of graphic presentations. Graphic options include grid, carpet, arrow and contour plots.

The script file in Figure 3.9 illustrates the input requirements for the COMPRT program. The coordinate files are required for all graphics. Contour and Carpet plots require input of the .PLT file containing the variable of interest. For arrow plots, files containing the two velocity components are required. The data example of Figure 3.9 is for contour plot generation. Other PLT types require slightly different questions and responses but are quite similar to the example shown.

```
FINAL SOLUTION
MAXIMUM # OF UPDATES ATTAINED

DENSITY
MULTIPLIER = 10.0E          -2

TEXT FOLLOWS
  104 105 109 113 116 118 118 118 116 115 114 113 112 111 110 109 108 107 105 10
4 103 103 102 102 101 101 101 100  98  96  93  91
  100 105 109 113 116 118 119 118 117 115 114 113 112 111 110 109 108 107 105 10
4 103 103 102 102 101 101 101 100  98  96  93  91
  100 104 109 113 117 118 119 118 117 115 114 113 112 111 110 109 108 107 106 10
4 103 103 102 102 101 101 101  99  98  95  93  91
  100 104 109 113 117 119 119 118 117 116 115 114 113 112 110 109 108 107 106 10
5 103 103 102 102 101 101 101  99  98  95  93  91
  100 104 109 113 117 119 119 118 117 116 115 114 113 112 111 109 108 107 106 10
5 104 103 102 102 102 101 101  99  97  95  93  90
  100 104 109 114 117 119 119 119 117 116 115 114 113 112 111 110 108 107 106 10
5 104 103 102 102 102 101 101  99  97  95  92  90
  100 104 109 114 117 119 120 119 118 116 115 114 113 112 111 110 109 107 106 10
5 104 103 102 102 102 101 101  99  97  95  92  90
  100 104 109 114 117 119 120 119 118 116 115 114 113 112 111 110 109 108 106 10
5 104 103 102 102 102 101 101  99  97  94  92  90
  100 104 109 114 118 120 120 119 118 117 116 115 114 113 111 110 109 108 107 10
5 104 103 102 102 102 101 101  99  97  94  92  89
  100 104 109 114 118 120 120 120 118 117 116 115 114 113 112 110 109 108 107 10
5 104 103 102 102 102 101 101  99  97  94  91  89
  100 104 109 114 118 120 120 120 118 117 116 115 114 113 112 110 109 108 107 10
6 104 103 103 102 102 101 100  99  97  94  91  89
  100 104 109 114 118 120 121 120 119 117 116 115 114 113 112 111 109 108 107 10
6 104 103 103 102 102 101 100  99  96  94  91  89
  100 104 110 114 118 120 121 120 119 117 116 115 114 113 112 111 110 108 107 10
6 104 103 103 102 102 101 100  99  96  93  91  89
  100 104 110 114 118 120 121 120 119 117 116 116 115 113 112 111 110 109 107 10
6 105 103 103 102 102 101 100  99  96  93  91  88
  100 104 110 114 118 121 121 120 119 118 117 116 115 114 112 111 110 109 107 10
6 105 104 103 102 102 101 100  98  96  93  90  88
  100 104 110 115 118 121 121 120 119 118 117 116 115 114 113 111 110 109 108 10
6 105 104 103 102 102 101 100  98  96  93  90  88
  100 104 110 115 118 121 121 120 119 118 117 116 115 114 113 111 110 109 108 10
6 105 104 103 102 102 101 100  98  96  93  90  88
  100 104 110 115 119 121 121 120 119 118 117 116 115 114 113 112 110 109 108 10
6 105 104 103 102 102 101 100  98  96  93  90  88
  100 105 110 115 119 121 121 121 119 118 117 116 115 114 113 112 111 109 108 10
7 105 104 103 102 102 101 100  98  96  93  90  88
  100 105 110 115 119 121 121 121 119 118 117 116 115 114 113 112 111 109 108 10
7 105 104 103 102 102 101 100  98  96  93  90  88
  100 105 110 115 119 121 121 120 119 118 117 116 115 114 113 112 111 110 108 10
7 106 104 103 103 102 102 100  98  96  93  91  88
  100 105 110 115 119 121 121 120 119 118 117 116 115 115 113 112 111 110 109 10
7 106 104 103 103 102 102 101  99  96  93  91  89
  100 105 110 115 119 121 121 120 119 118 117 116 116 115 114 112 111 110 109 10
8 106 105 103 103 102 102 101  99  96  94  91  89
  100 105 111 116 119 121 121 120 119 118 117 117 116 115 114 113 112 110 109 10
8 106 105 104 103 102 102 101  99  97  94  92  90
  100 105 111 117 120 122 121 121 119 118 117 117 116 115 114 113 112 111 109 10
8 107 105 104 103 103 102 101  99  97  94  92  91
  100 106 112 118 121 122 122 121 120 119 118 117 116 116 115 114 112 111 110 10
9 107 106 104 103 103 102 102 100  98  96  94  92
  100 106 113 118 122 123 123 121 120 119 118 118 117 116 115 114 113 112 111 10
9 108 106 105 104 103 103 103 102 101  98  97  95
  100 106 113 119 123 124 123 122 121 120 119 118 118 117 116 115 114 113 111 11
0 109 107 105 104 104 104 104 104 103 101  99  98
  100 106 114 120 124 125 124 123 121 120 120 119 118 118 117 116 115 113 112 11
1 109 108 106 105 104 104 105 105 105 104 103 102
  100 106 114 121 125 125 125 124 122 121 120 120 119 119 118 117 116 114 113 11
2 110 109 107 106 105 105 106 107 108 107 106 105
  100 107 115 122 125 126 126 124 123 122 121 121 120 120 119 118 117 115 114 11
3 111 110 108 107 106 106 107 109 110 110 110 109
  100 107 115 122 126 127 127 126 124 123 122 122 121 121 120 119 118 117 115 11
4 112 111 109 108 107 106 108 111 114 114 114 113
  100 107 115 123 127 128 128 127 126 124 124 123 123 122 121 120 119 118 116 11
5 113 112 110 109 107 107 110 114 117 118 118 117
  100 107 115 123 128 129 129 128 127 126 125 125 124 123 123 122 121 119 118 11
6 115 113 111 110 108 108 111 117 121 122 121 121
  100 106 115 124 129 130 130 129 128 127 127 126 126 125 124 123 122 121 119 11
7 116 114 112 111 109 110 114 121 125 125 125 125
  100 106 115 124 129 131 131 131 130 129 128 128 127 126 126 125 124 122 121 11
9 117 115 114 112 111 111 117 126 130 129 129 129
  100 106 115 124 130 132 133 132 131 130 130 129 129 128 127 126 125 124 122 12
```

Figure 3.5 Density field print (ifile.72)

```
0 118 116 115 113 112 113 120 130 134 133 134 133
  100 106 115 124 131 133 134 134 133 132 131 131 130 130 129 128 127 125 124 12
2 120 118 116 114 113 115 123 135 138 137 137 136
  100 106 115 124 131 135 136 135 135 134 133 133 132 132 131 130 128 127 125 12
3 121 119 117 115 114 117 128 140 142 141 141 139
  100 106 115 124 132 135 137 137 136 135 135 134 134 133 132 131 130 129 127 12
5 123 120 118 116 115 120 133 145 145 144 144 143
  100 106 115 124 132 136 138 138 138 137 136 136 136 135 134 133 132 130 128 12
6 124 122 119 117 117 123 139 150 148 148 147 146
  100 105 114 124 132 137 139 139 139 138 138 138 137 137 136 135 133 132 130 12
8 125 123 120 118 118 126 144 154 151 151 149 149
  100 105 114 124 132 137 140 141 140 140 140 139 139 138 137 136 135 133 131 12
9 127 124 121 119 119 130 150 158 153 155 152 152
  100 105 114 124 132 138 141 142 142 141 141 141 140 140 139 138 136 135 133 13
0 128 125 122 120 121 134 156 161 156 158 154 155
  100 105 114 124 132 138 141 143 143 143 142 142 142 141 140 139 138 136 134 13
2 129 126 123 121 122 137 161 163 159 160 157 158
  100 105 113 123 132 138 142 143 144 144 143 143 143 142 141 140 139 137 135 13
3 130 127 124 121 124 141 165 165 162 162 159 160
  100 105 113 123 132 138 142 144 145 145 144 144 144 143 142 141 140 138 136 13
3 131 128 125 122 125 145 169 167 164 164 161 162
  100 105 113 123 132 139 143 144 145 145 145 145 145 144 143 142 141 139 137 13
4 131 128 125 123 127 148 172 167 166 165 162 163
  100 104 113 123 132 139 143 145 146 146 146 146 146 145 144 143 141 139 137 13
5 132 129 126 123 128 151 174 168 168 166 164 164
  100 104 113 123 132 139 143 145 146 146 146 146 146 145 144 143 142 140 138 13
5 132 129 126 123 129 154 176 168 168 165 164 164
  100 104 113 123 132 139 143 145 146 146 146 146 146 146 145 143 142 140 138 13
5 133 129 126 123 130 156 178 169 170 167 166 165

 TEXT FOLLOWS
   89  87  86  84  83  82  81  80  79  79  79  78  78  78  78  78  78  78  78
   89  87  86  84  83  82  80  80  79  79  79  79  78  78  78  78  78  78  78
   89  87  85  84  83  81  80  80  79  79  79  79  78  78  78  78  78  78  78
   89  87  85  84  83  81  80  80  79  79  79  79  79  78  78  78  78  78  78
   88  87  85  84  82  81  80  80  79  79  79  79  79  78  78  78  78  78  78
   88  86  85  84  82  81  80  80  79  79  79  79  79  79  78  78  78  78  78
   88  86  85  83  82  81  80  80  79  79  79  79  79  79  79  79  78  78  78
   88  86  85  83  82  81  80  80  79  79  79  79  79  79  79  79  79  79  79
   88  86  84  83  82  81  80  80  79  79  79  79  79  79  79  79  79  79  79
   87  86  84  83  82  81  80  80  79  79  79  79  79  79  79  79  79  79  79
   87  85  84  83  82  81  80  80  80  79  79  79  79  79  79  79  79  79  79
   87  85  84  83  82  81  80  80  80  79  79  79  79  79  79  79  79  79  79
   87  85  84  83  82  81  80  80  80  79  79  79  79  79  79  79  79  79  79
   87  85  84  83  82  81  81  80  80  79  79  79  79  79  79  79  79  79  79
   86  85  84  83  82  81  81  80  80  80  79  79  79  79  79  79  79  79  79
   86  85  84  83  82  81  81  80  80  80  80  79  79  79  79  79  79  79  79
   86  85  84  83  82  81  81  80  80  80  80  80  79  79  79  79  79  79  79
   86  85  84  83  82  82  81  81  80  80  80  80  80  79  79  79  79  79  79
   86  85  84  83  82  82  81  81  81  80  80  80  80  80  80  80  80  80  80
   86  85  84  84  83  82  82  81  81  81  80  80  80  80  80  80  80  80  80
   87  86  85  84  83  83  82  82  81  81  81  81  81  81  81  81  81  81  81
   87  86  85  85  84  83  83  82  82  82  82  82  81  81  81  81  81  81  81
   88  87  86  85  85  84  84  83  83  83  82  82  82  82  82  82  82  82  82
   89  88  87  86  85  85  84  84  84  83  83  83  83  83  83  83  83  83  83
   89  89  88  87  86  86  85  85  84  84  84  84  84  84  84  84  83  83  83
   91  90  90  89  88  88  87  87  86  86  86  86  85  85  85  85  85  85  85
   94  93  93  92  91  91  90  89  89  89  88  88  88  88  88  88  88  88  88
   97  97  96  95  95  94  93  92  92  92  91  91  91  91  91  91  91  91  91
  101 100 100  99  99  98  97  96  96  95  95  95  94  94  94  94  94  94  94
  105 104 104 103 103 102 101 100  99  99  99  98  98  98  98  98  98  98  98
  108 108 108 107 107 106 105 104 103 103 102 102 102 102 102 102 102 102 101
  112 112 112 111 111 110 109 108 108 107 106 106 106 106 106 106 105 106 105
  117 116 116 115 115 114 114 113 112 111 111 110 110 110 110 110 109 109 109
  121 120 120 119 119 119 118 117 116 115 115 114 114 114 113 113 113 113 113
  124 124 124 124 123 123 122 121 120 119 119 118 118 118 117 117 117 117 117
  129 128 128 128 127 127 126 126 124 124 123 122 122 122 121 121 121 121 121
  133 132 132 132 131 131 130 130 128 128 127 126 126 126 125 125 125 125 125
  136 136 135 135 135 135 134 133 132 131 130 130 129 129 129 129 128 129 128
  140 139 139 138 138 138 138 137 136 135 134 133 133 132 132 132 132 132 132
  143 142 142 142 142 141 141 140 139 138 137 136 136 135 135 135 135 135 135
  146 145 145 145 145 144 144 143 142 141 140 139 139 138 138 138 138 137 138
  148 148 148 147 147 147 147 146 145 144 143 142 142 141 141 140 141 140 141
  151 151 150 150 150 150 150 148 148 146 146 144 144 143 144 142 143 142 143
  153 154 153 153 152 152 152 151 150 149 148 147 147 145 146 145 146 144 145
  156 156 155 155 155 154 154 153 153 151 151 149 149 148 148 147 148 147 148
  158 158 157 157 156 156 156 155 154 153 152 151 150 149 149 149 149 148 149
  159 160 159 159 158 158 157 157 156 155 154 153 152 152 151 151 151 151 151
  161 161 160 160 159 159 158 158 157 156 154 154 153 153 152 152 151 151 151
  162 163 161 162 160 161 159 160 158 158 156 156 154 155 153 154 153 154 153
  162 162 160 161 160 161 159 160 157 158 155 156 153 154 152 153 152 153 151
  163 164 162 163 161 162 160 162 159 160 157 158 155 156 154 156 153 156 154
```

Figure 3.5 Density field print (ifile.72)

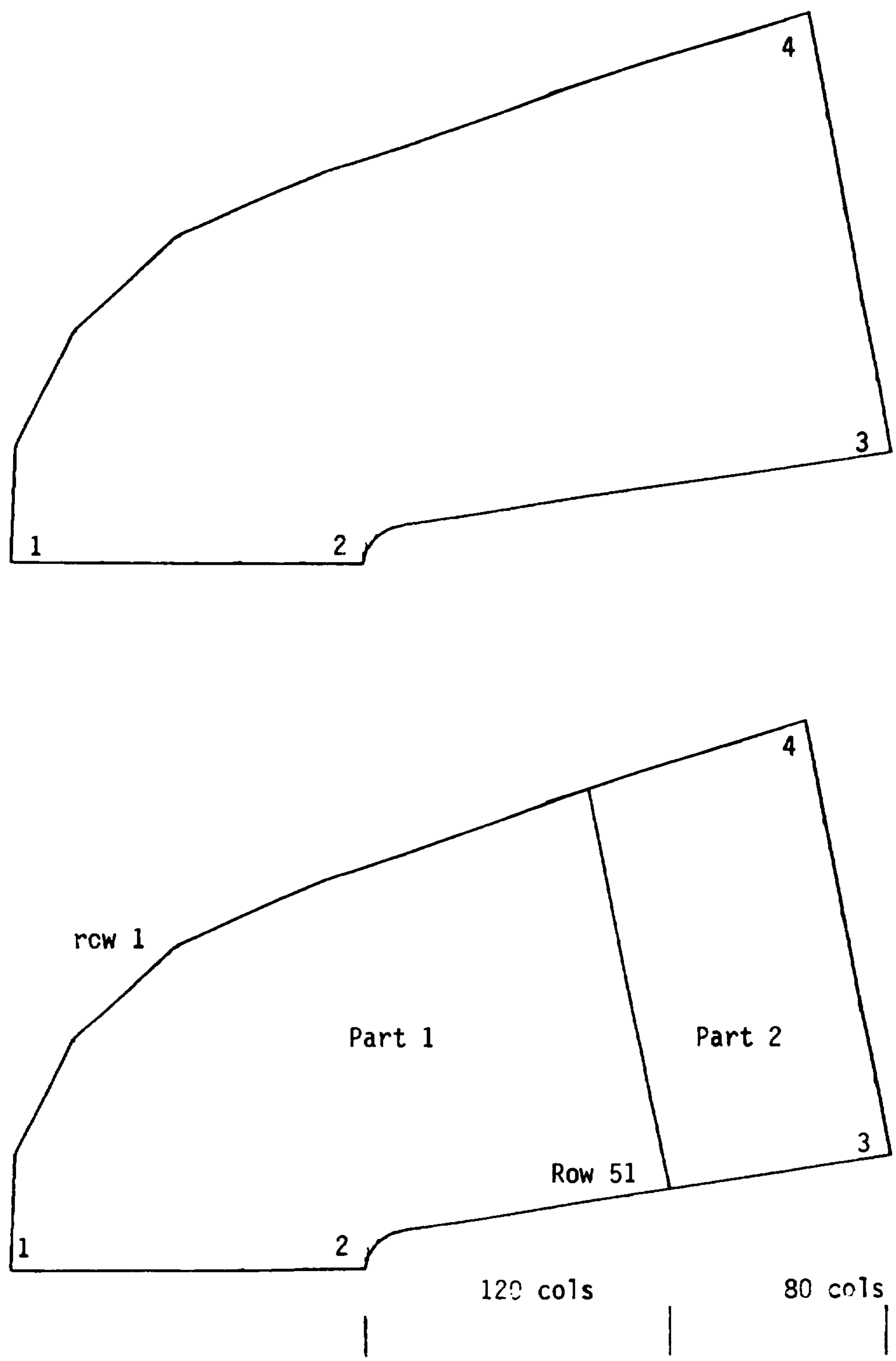


Figure 3.6 Print mapping procedure

DENSITY MULTIPLIER = 10.0E	-2
X-COMPONENT OF VELOCITY MULTIPLIER = 10.0E	-2
Y-COMPONENT OF VELOCITY MULTIPLIER = 10.0E	-3
ENERGY MULTIPLIER = 10.0E	-2
PRESSURE MULTIPLIER = 10.0E	1
X-COMPONENT OF MOMENTUM MULTIPLIER = 10.0E	-1
Y-COMPONENT OF MOMENTUM MULTIPLIER = 10.0E	-2
TOTAL PRESSURE MULTIPLIER = 10.0E	1

X-COURANT # DISTRIBUTION
MULTIPLIER = 10.0E
	-3

Y-COURANT # DISTRIBUTION
MULTIPLIER = 10.0E
	-4

GRID X-COORDINATE MAP MULTIPLIER = 10.0E	-4
GRID Y-COORDINATE MAP MULTIPLIER = 10.0E	-4

Figure 3.7 Primary physical variables output (ifile.72)

```
 enter grid size, nx,ny,nz
51 51 1
 enter input name
xcoord
  0.4336690065E-02  0.2923670039E-01
STOP
```

Figure 3.8   Script file for a pltout session

```
 SELECT MODE:

   1.  Completely new run
   2.  All the same options as last time
1

 SELECT MODE:

   1.  END
   2.  individual files
   3.  carpet plot
   4.  arrow plot
   5.  planar-grid  plot
   6.  contour  plot

   ENTER SELECTION:
2
 SELECT MODE:

   1.  END
   2.  already made this choice (individual files)
   3.  carpet plot
   4.  arrow plot
   5.  planar-grid  plot
   6.  contour  plot

   ENTER SELECTION:
4

 Enter the iqsize of the grid  (x1planes,x2planes,x3planes).

Example: IQSIZE= 29x11x5 would be 29 11 5,   enter 3 integers
51 51 1

 Enter name of the file containing the x values.
xcoord.plt

 Enter name of the file containing the y values.
ycoord.plt

 Enter name of the file containing the first arrow values.
xvel.plt

 Enter name of the file containing the second arrow values.
yvel.plt
STOP
```

Figure 3.9   Script file for an arrows comprt session

Following execution of COMPRT, the grid and carpet plots can be viewed by ensuring that the COMPRT output is transferred to a file called three.d and executing the display module GSHOWEX. Arrow plots first require execution of the arrow program. For contour plots, the procedure is different. Contour plots require execution of the programs PREJR and JREX for display. The execution procedures for each plot type are summarized in Table 3.1.

The graphics operate on SGI and RS-6000 workstations having the GL graphics board or on any machine having the DuPont GL graphics converter program. Once on the screen, size and position can be controlled through keyboard and mouse interaction. The controls and their meanings are illustrated in Table 3.2.

Table 3.1 Plot Execution Sequencies

GRID

```
pltout  xcor.plt , ycor.plt
comprt  (grid)
gshowex
```

CARPET

```
pltout  xcor.plt, ycor.plt, variable.plt
comprt  (carpet), copy output to three.d
gshowex
```

ARROW

```
pltout  xcor.plt, ycor.plt, u1.plt, u2.plt
comprt  (arrow)
arrow   (arrow size is in arrow.data default=5)
gshowex
```

CONTOUR

```
pltout  xcor.plt, ycor.plt, variable
comprt  (contour)
prejr
jrex
```

Table 3.2 On-Screen Graphics Commands

COMMAND*	ACTION
keyboard	
+	enlarges the figure
-	shrinks the figure
p	returns to initial position and size
arrows	translate in arrow direction
F	perform operation faster
1	rotate 90° about X1 axis
2	rotate 90° about X2 axis
3	rotate 90° about X3 axis
R (with mouse)	reverse rotation
Enter	terminate graphic
mouse	
button 1	rotate about X1 axis
button 2	rotate about X2 axis
button 3	rotate about X3 axis

*press and hold button to get effect

4.0 AXISYMMETRIC BLUNTBODY SUPERSONIC FLOW

This section illustrates the input process for an axisymmetric blunt body flowfield at Mach 2. The required data is generated by executing the mkblunt program to fill the body file. Next, the MDATA file is edited to reflect the grid size. Finally, the sfill2 module is executed to complete the time, initial and boundary conditions data.

4.1 BODY FILE GENERATION

The process follows Table 2.2 and begins with input of a few parameters which describe the body shape, flow-speed and finite element grid allocations. These are input via a Q/A session with execution module mkblunt. The data requirements are illustrated graphically in the sketch presented in Figure 4.1, where the coordinate system origin is upstream of the nose, ri is the nose sphere radius, θ is the body angle, A is the angle at which the body line is tangent to the sphere (90-θ) and m_{00} is the freestream Mach No. The coordinates of the flow domain extremes are also required as noted in Figure 2.1. Finally, grid attraction along the boundary layer and bow-shock lines is important; these are sketched on the figure for reference.

The Q/A session for the data of Figure 4.1 was captured in a script file as presented in Figure 4.2. The generated "body" file is illustrated in Figure 4.3. The body shape and size are determined from the first two answers and the coordinates of the flow domain boundaries are given by answers, 3 thru 5 questions. Note that the upstream boundary isn't required since it is determined internally by an analytical bow-shock calculation based upon the flow Mach number. The other data are self-explanatory except for the grid attraction factors at the end. The factors are applied at macro element boundaries, generally parallel to the body surface and outer boundary (see Figure 4.1). The respective factors are labeled proceeding from the body surface to the outer boundary as follows:

Surface line	=	.1
Boundary layer line	=	0.
Mid plane line	=	.05
Bow shock line	=	-.3
Outer boundary line	=	-.174

The attraction values along each grid line cause the grid between the lines to be attracted to, or repelled from, the line depending on the absolute values of adjacent factors. For example: a surface factor of .1 together with boundary layer factor of 0. causes the grid between to be attracted to the surface line. The difference between .1 and 0. determines the degree of attraction.

After executing the bgrid and ref modules, a graphic display of the grid can be obtained by typing gshowex. The grid plot is illustrated in Figure 4.4. Note the grid attraction along the anticipated bow shock path and along the boundary layer line. Grid attraction can be modified in the body file.

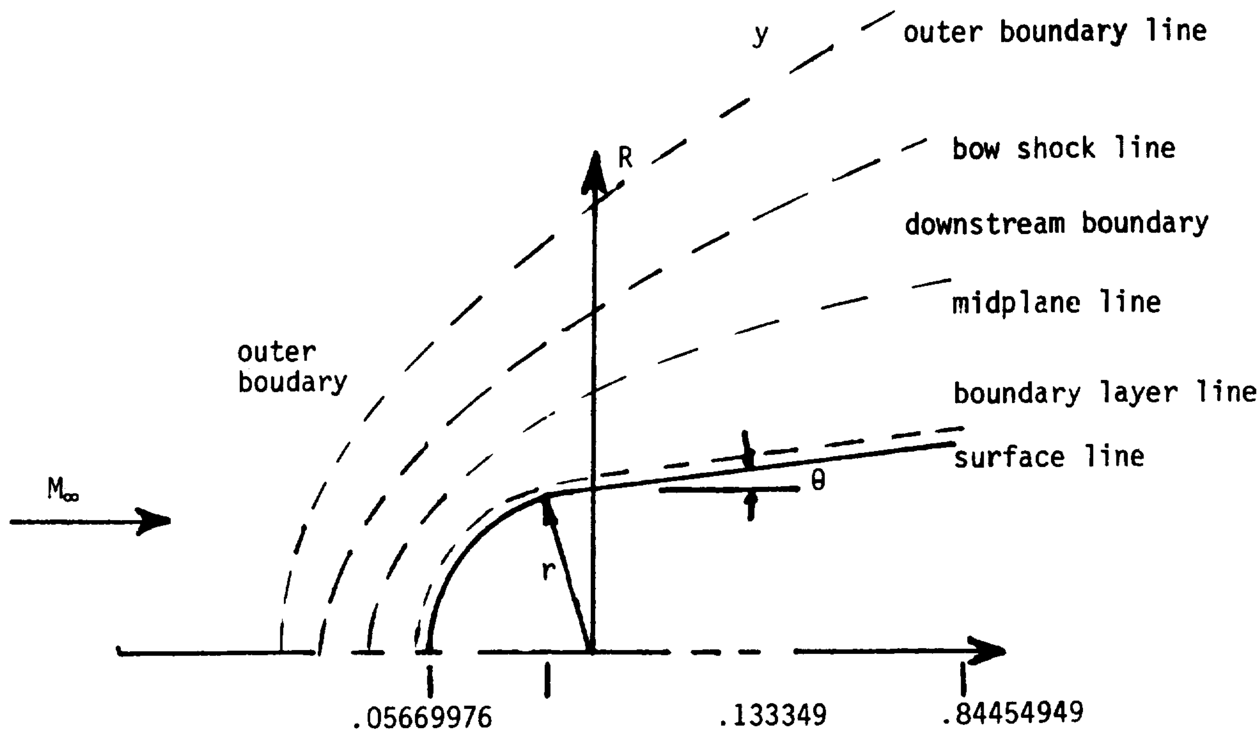


Figure 4.1 Sphere/cone blunt-body (axisymmetric)

```
 enter blunt nose radius (meters)
.0127
 enter body angle (degrees)
10.5
 enter x coordinate of blunt tip nose (meters)
.05669976
 enter x coordinate at tail (meters)
.84454949
 enter maximum x coordinate of outer boundary (meters)
.133349
 enter number of nodes, tip to tail
51
 enter number of nodes, tip to outer boundary
51
 enter new freestream mach number
2.
 enter old freestream mach number
 (0 if first time)
0.
  The grid attraction factors are:
   0.1000000015      0.0000000000E+00  0.5000000075E-01 -0.3000000119     -0.174
9999970
  Change them? ("y"/"n")
'n'
STOP
```

Figure 4.2 Blunt-body module (mkblunt) q/a session

```
   51   51
   .13334900    .05699760    .84454989
   50
   50
  2.00000000
   .00000000
   .01270000
   .00000000
 79.50000000
   .00000000
   .10000000    .00000000    .05000000   -.30000001   -.17500000
```

Figure 4.3 Generated "Body" file

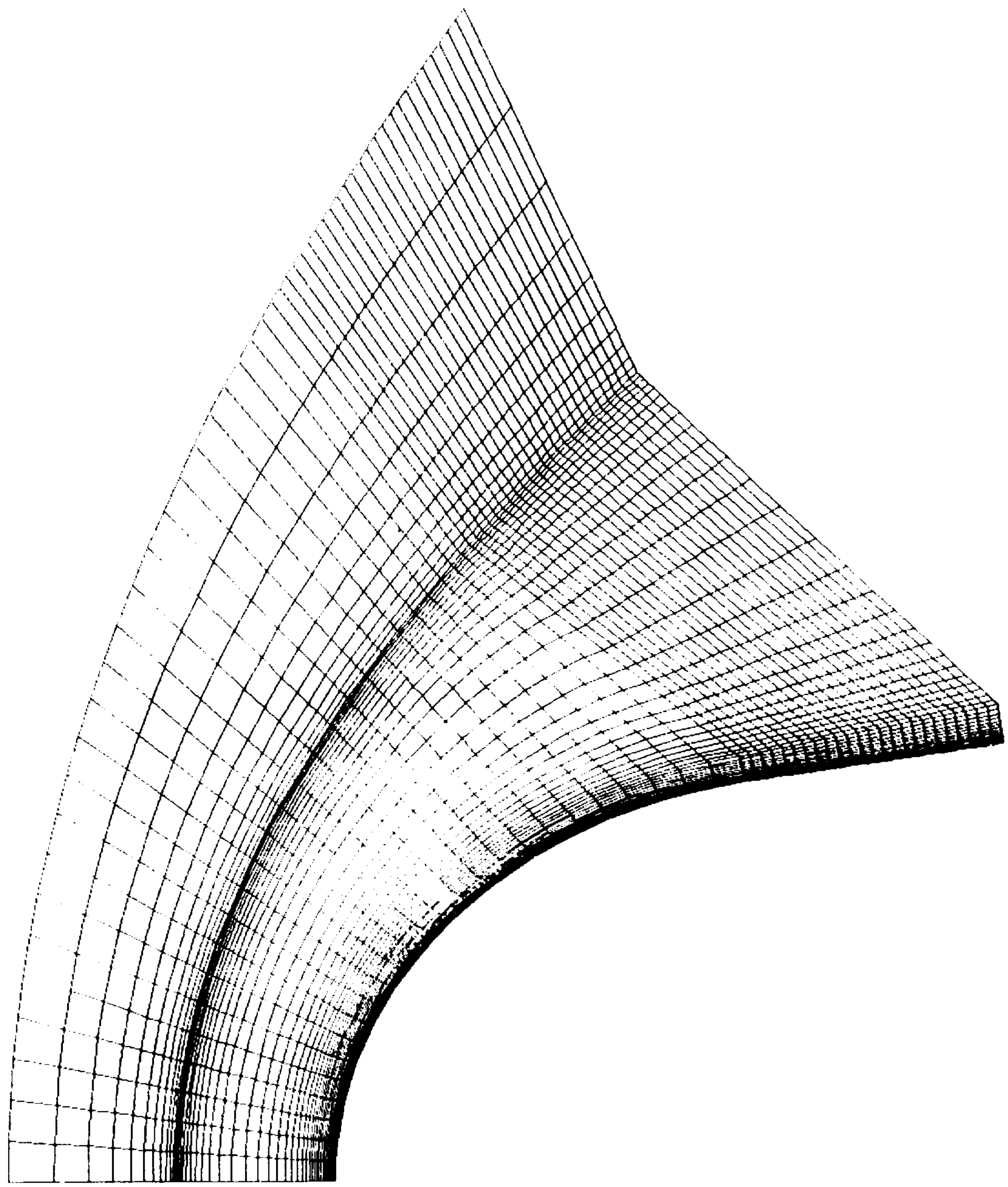


Figure 4.4. Grid for blunt-body test case

4.2 MDATA.in FILE GENERATION

Before the ICPLT module can be executed (see Table 2.2) the MDATA.in file (Figure 4.5) must be prepared. This can be done using a text editor of choice to modify the array sizes and the initial values of density (rho) and total energy (e). The MDATA.in file is illustrated in Figure 2.4. The variables of interest are under the names "iqnow" and "iqsize." Under iqnow, the entire array for each variable is initialized. The size of the arrays must correspond with the grid size specification in the "body" file. In this case 51 rows of 51 columns each are specified. In addition, a global value is applied to density (rho=.280798) and energy (e=.60255). The grid size also requires adjustment of the first two values under IQSIZ where the first value represents the nodes along the body and the second value is the number of rows between the body and outer boundary line.

With completion of the MDATA.IN file, the ICPLT module can be executed to generate the initial velocity distribution. An arrow plot of the flowfield can then be obtained by executing the arrow and GSHOWEX modules to verify correctness. The arrow plot for the bluntbody flow is illustrated in Figure 4.6. Screen graphics control is reviewed in section 3.2. Note that the outer boundary flow is uniform and the velocity magnitudes decrease to zero at the body surface.

4.3 BOUNDARY AND INITIAL CONDITION DATA (SFILL2 Module)

The final data preparation required prior to execution of FEMNS is the initial and boundary condition data. These are input via the interactive program SFILL2 which fills the files ifile.63 and ifile.65 through ifile.69. Before executing SFILL2 it is good to have a sketch of the flow domain handy for grid orientation. These are illustrated in Figure 4.7. In Figure 4.7a, the row/column orientation is illustrated (also see section 2.2). The grid numbering proceeds in rows in the direction of the columns. The side numbering is counter-clockwise beginning at the lower left.

Boundary conditions are as illustrated in Figure 4.7. Side 1 is a symmetry plane. Side 2 is the bluntbody surface where velocity is zero. Side 3 is a downstream surface where only the pressure is held constant. Side 4 contains prescribed freestream conditions for the density, energy and velocity components which are held constant throughout the solution evolution. Each of the corners are numbered such that the corner number is the same as the side following it.

The SFILL2 input requirements are explained in section 2.2 and Appendix A. The data in Appendix A is for this case and is explained extensively here, relative to the previous discussion and Figure 4.7.

The problem has four corners and four sides where boundary data is required. Proceeding from corner 1 in Figure 4.7a, the responses to the boundary condition questions in SFILL2 are as follows:

SECTION				FIRST NODE	LAST NODE
1	Corner 1	Inflow B.Corner	all fixed	Lnode1, EL 1,1	Lnode1, EL 1,1
2	Side 1	Inflow Boundary	mx fixed (0)	Lnode2, EL 1,1	Lnode1, EL 1,50
3	Corner 2	Inflow Boundary	mx,my fixed	Lnode2, EL 1,80	Lnode2, EL 1,80
4	Side 2	Wall Boundary	mx,my fixed	Lnode3, EL 1,50	Lnode2, EL 50,50
5	Corner 3	Outflow Boundary	mx,my fixed	Lnode3, EL 50,50	Lnode3, EL 50,50
6	Side 3	Outflow Boundary		Lnode4, EL 50,80	Lnode3, EL 50,1
7	Corner 4	Outflow Boundary	all fixed	Lnode4, EL 50,1	Lnode4, EL 50,1
8	Side 4	Inflow Boundary	all fixed	Lnode1, EL 80,1	Lnode4, EL 1,1

Note that the symmetry plane (side 1) is considered an inflow boundary with MY fixed to zero.

With completion of the input data, the bluntbody example case is run by executing the FEMNAS module. Execution in the background frees the window for other tasks. The run can be interrogated during execution by displaying the ifile.74 file via the tail command (ie: tail ifile.74-f) which is terminated with a **CONTROL C** command.

At the final step (300 in this case) FEMNAS prints the solution variables and terminates. Graphical presentation of the results can be obtained as explained in section 3. The results for the example case after 300 steps are plotted in Figures 4.8 to 4.10.

```
 6. T  INTEGRATION PARAMETERS
 0. 1.E-1 1E-4 1 128 .5 2 .5 T XP,HP,EPS,THETA,DTLIM,DQMIN,PFAC
 6  T  STEPPING PARAMETERS
   1  1 T  NSTEPS,NITERS
 1.  T  ICOEFN
     0.0, 1.0, -1., 0.0, 0.0        $ HT,ONE,-ONE,DUM1,DUM2
   1.E-2, 1.E-4, .1, 1.0, 0.0        $ REI,RE2I,GR,PEI,SINTH
   0.0, 0.0, 0.0, 0.0, 0.0        $ ZERO,-RE2I,BC1,BC2,BC3
   0.0, 0.0    T BC4,DUM3
 9  T  IFIXL
   1   $  FIXED NODES SET  , U1
   2   $  FIXED NODES SET  , U2
   3   $  FIXED NODES SET  , TEMP
   4   $  FIXED NODES SET  , PHI
   5   T  FIXED NODES SET  , SPHI
 4. T  IQNOW
    51(51*1.)    $ X1    1
    51(51*2.)    $ X2    2
    51(51*3.)    $ X3    2
    51(51*1.)    $ U1    3
    51(51*0.)    $ U2    4
    51(51*0.280797959252467325)   $ RHO
    51(51*0.602550268869117958)   T E
 4   T  IQSIZE
   51 51  1  48  43        T  N1,N2,N3
 10  T  IPRINT
  1005  1 100 1 2 3  34I1 4   T NPMOD,NSTRT,NSTOP,PVARS
 20 T  DEBUG
  0  1 8  1  0  1  1001 1002  1006 T 1010 1011 T KD,IT,NODE,EQN,TERM,PLN
    T T T
   (5F14.6)
U1  U2  TEMPPHI SPHIPRESTAU1TAU2ST  TR  USJNNU  MTRLDETJDETCETKJEJK2EJK3EJK4EJK
EJK6EJK7EJK8EJK9NLX2U1L U2L TEMLPHILSPHLF1  F2  F3  F4  F5  G1  G2  G3  G4  G5
X1  X2  ONESFX1FX2FX3FX4FX5
     INS2D  DUCT FLOW MODEL, CASE 1
END
```

Figure 4.5   MDATA.IN File

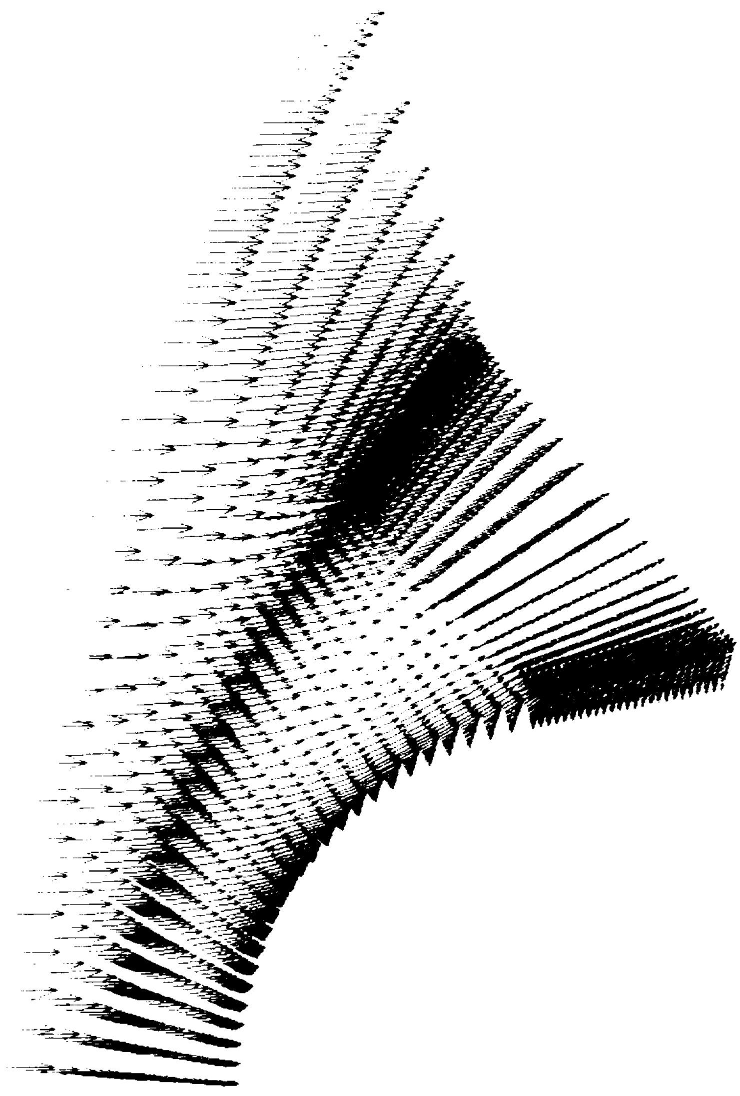
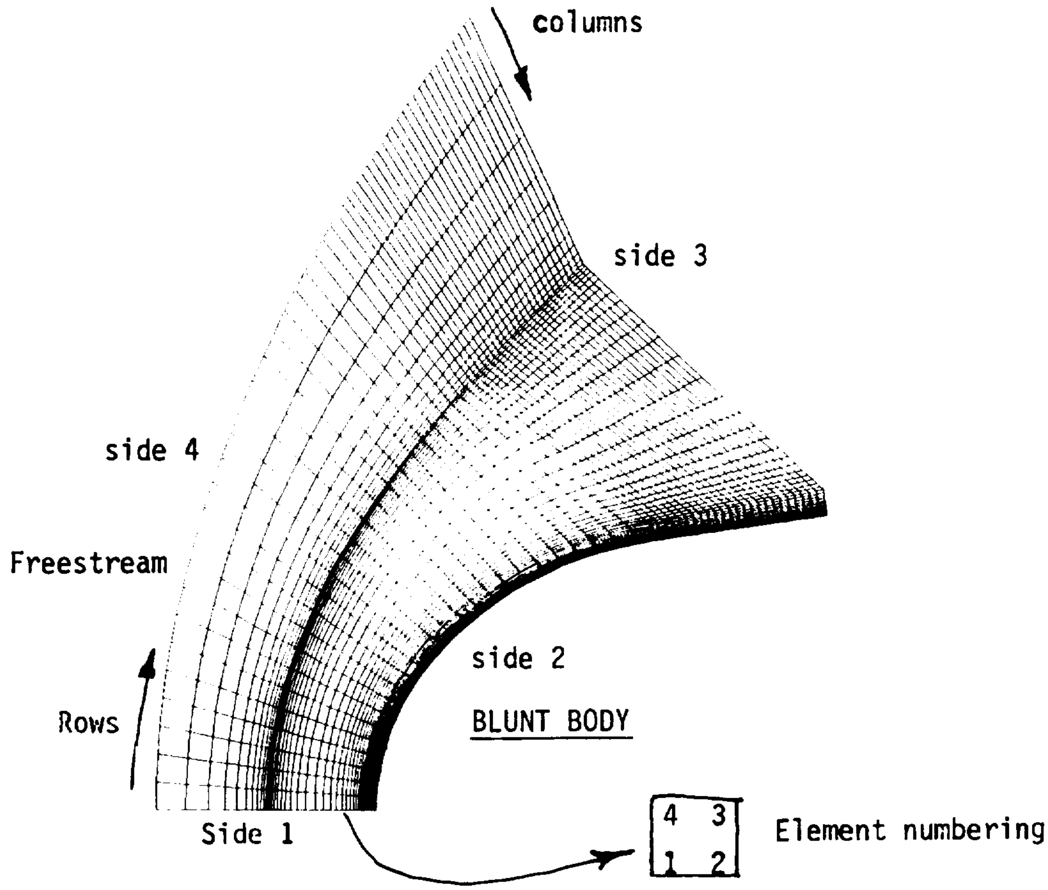
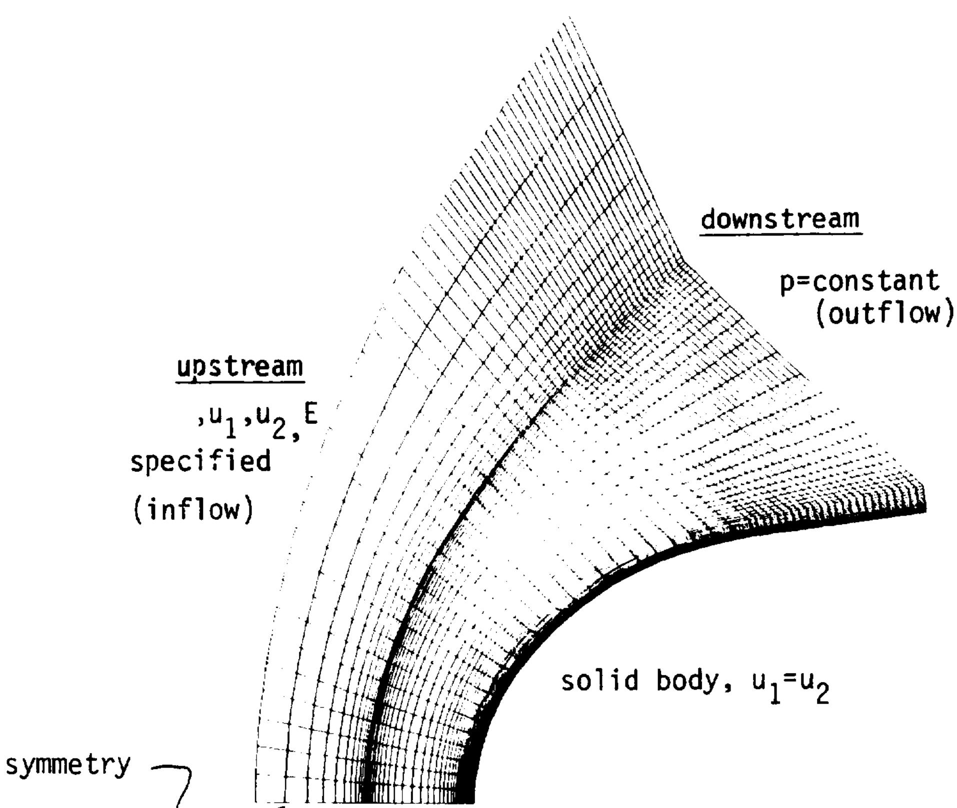


Figure 4.6   Blunt-body initial flowfield (Mach 2)



a.) Flow Domain and F.E. Grid



b.) boundary conditions

Figure 4.7. Axisymmetric Blunt-body Initial and boundary conditions

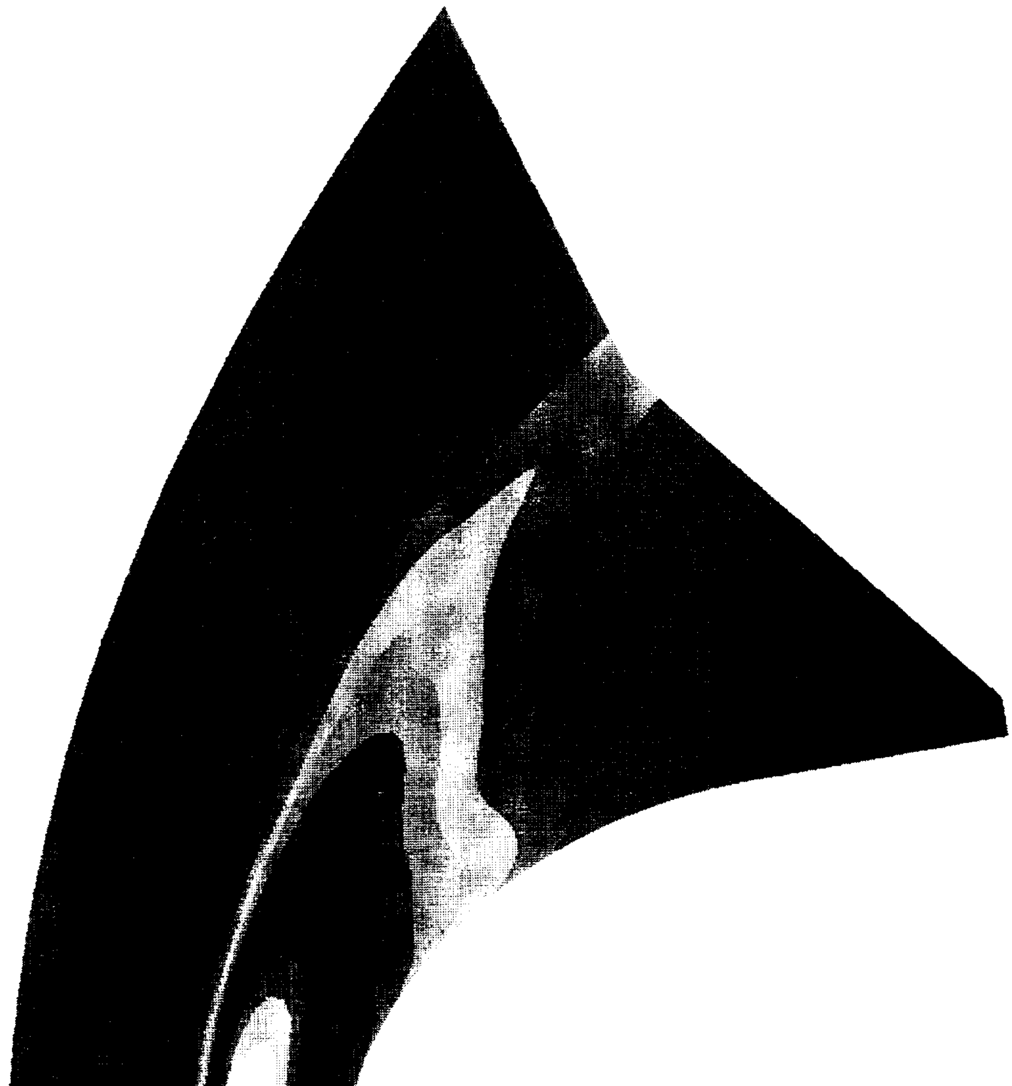


Figure 4.8 Density, Mach 2 blunt-body after 300 steps

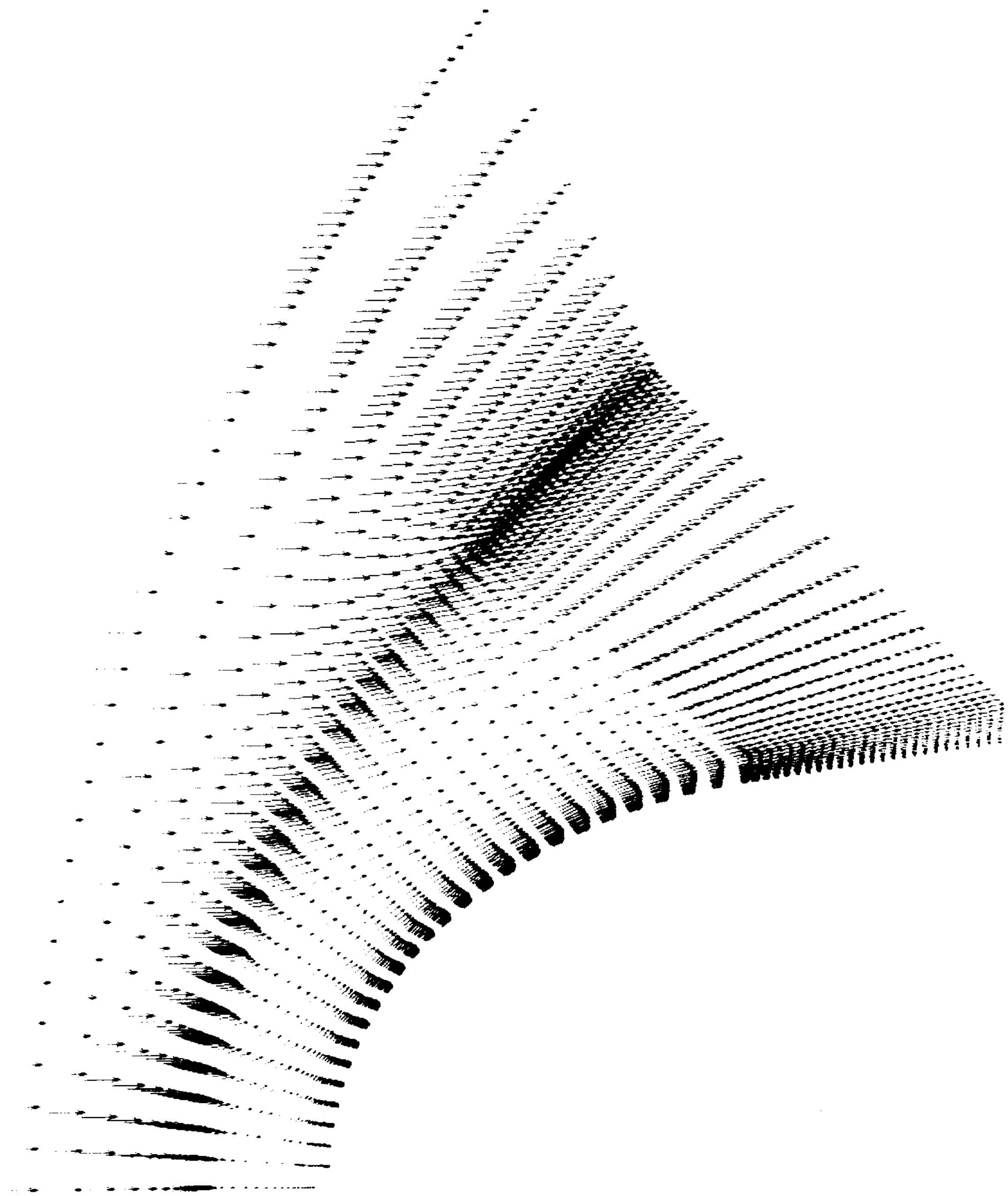


Figure 4.9 Velocity profile, Mach 2 blunt-body, 300 steps

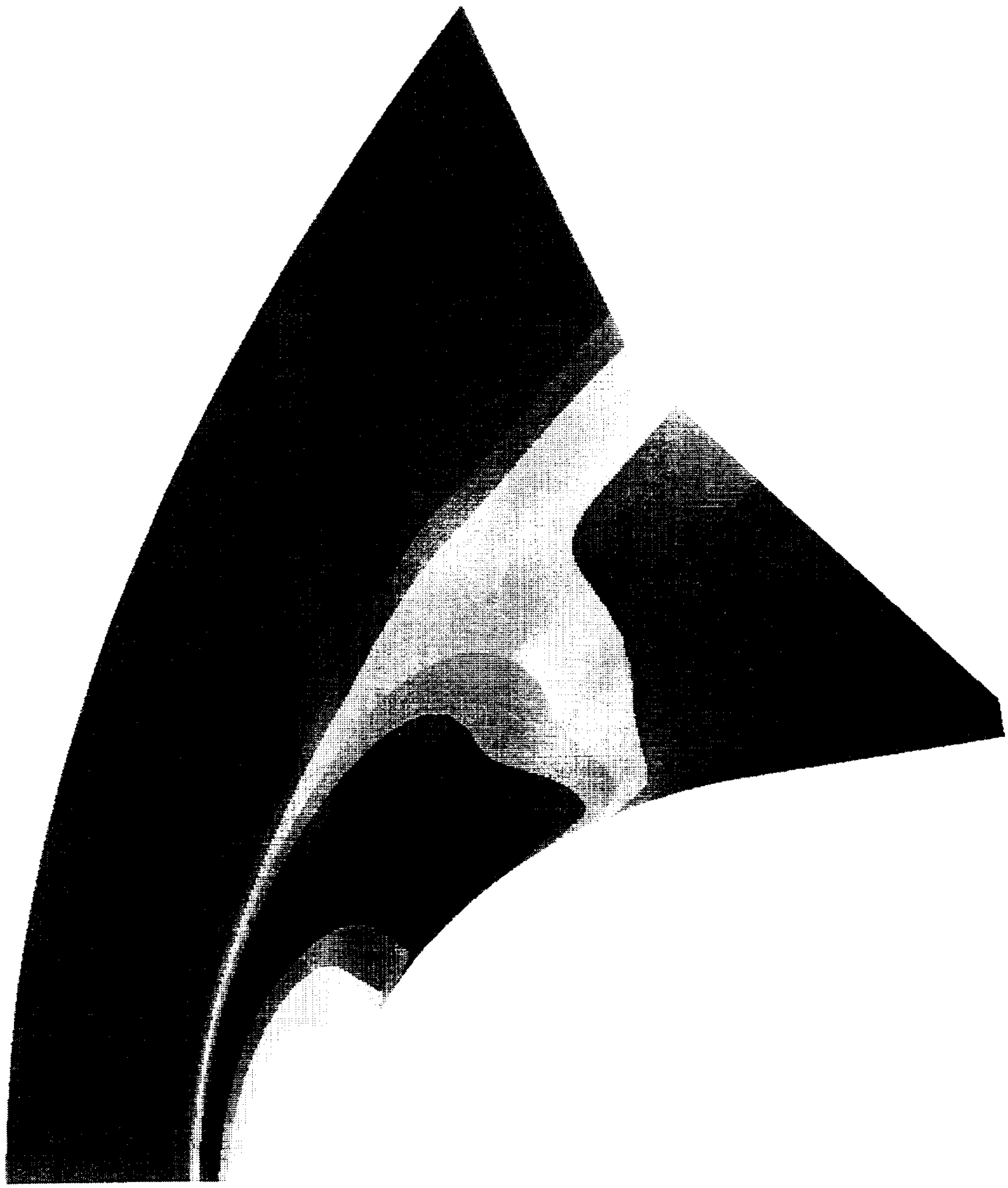


Figure 4.10   Energy, Mach 2 blunt-body, 300 steps

5.0 THREE-DIMENSIONAL AERODYNAMICS MACRO GRID

One of the more difficult tasks of setting up a 3D finite element Navier-Stokes model involves generation of the finite element grid. Not only is it necessary for the grid boundaries to accurately conform to the aerodynamic surface in a regular and smooth way but the mesh needs to be easily changed to adapt the mesh for grid refinement in areas where the primary flow variables are most significantly changing. To adequately satisfy both of these criteria, a second degree polynomial finite element interpolation methodology similar to that used for the 2D models of Section 2 was developed. Second degree elements (MACRO ELEMENTS) are user defined over the aerodynamic surface (Figure 5.1). These are extended into the air space around the surface to form a 3-dimensional mesh of hexahedrons. The gridding program refines the macro grid to form the computational mesh. Extensive variation in grid refinement and attraction is readily achieved by changing a few grid control parameters rather than having to respecify any gridpoints data. The principal data required for a macro grid specification consists of:

1. MACRO ELEMENT DATA
2. MACRO GRID DATA
3. MACRO ELEMENT STACKING DATA

Each of these is described in detail in the following sections. Before beginning, however, numbered sketches are useful for guiding the input process. Figure 5.2 presents a wing fuselage surface section of the generic fighter test case presented in Figure 5.1. Fifteen macro elements are defined and numbered. The macro nodes are also numbered for reference. Note that curved sides require specification of a mid-side node and the macro element numbers coincide with the first node of each macro element.

An estimate of the number of finite elements to be generated in each macro element is useful. These are illustrated in Figure 5.3 as circled numbers. The total number of finite elements generated over a surface macro element is obtained from the product of the edge values in Figure 5.3. For example, macro element [38] is to be subdivided into 9 finite elements (3x3).

The 3-dimensional macro elements are completed by connecting the surface plane of figures 5.2 and 5.3 with lines extending into the air space to adjacent planes having a similarly divided macro grid. Six planes extending below and above the numbered plane of figures 5.2 and 5.3 are illustrated in Figure 5.4. The number of finite elements between planes is illustrated (circled numbers) in Figure 5.4. Using the information in Figures 5.2-5.4, the macro-grid data can be created via a line text editor. The specific data requirements and formats follow.

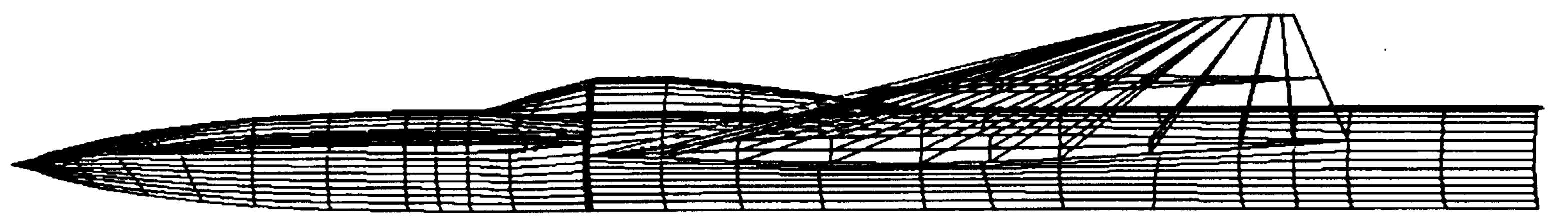


Figure 5.1 Generic fighter surface grid

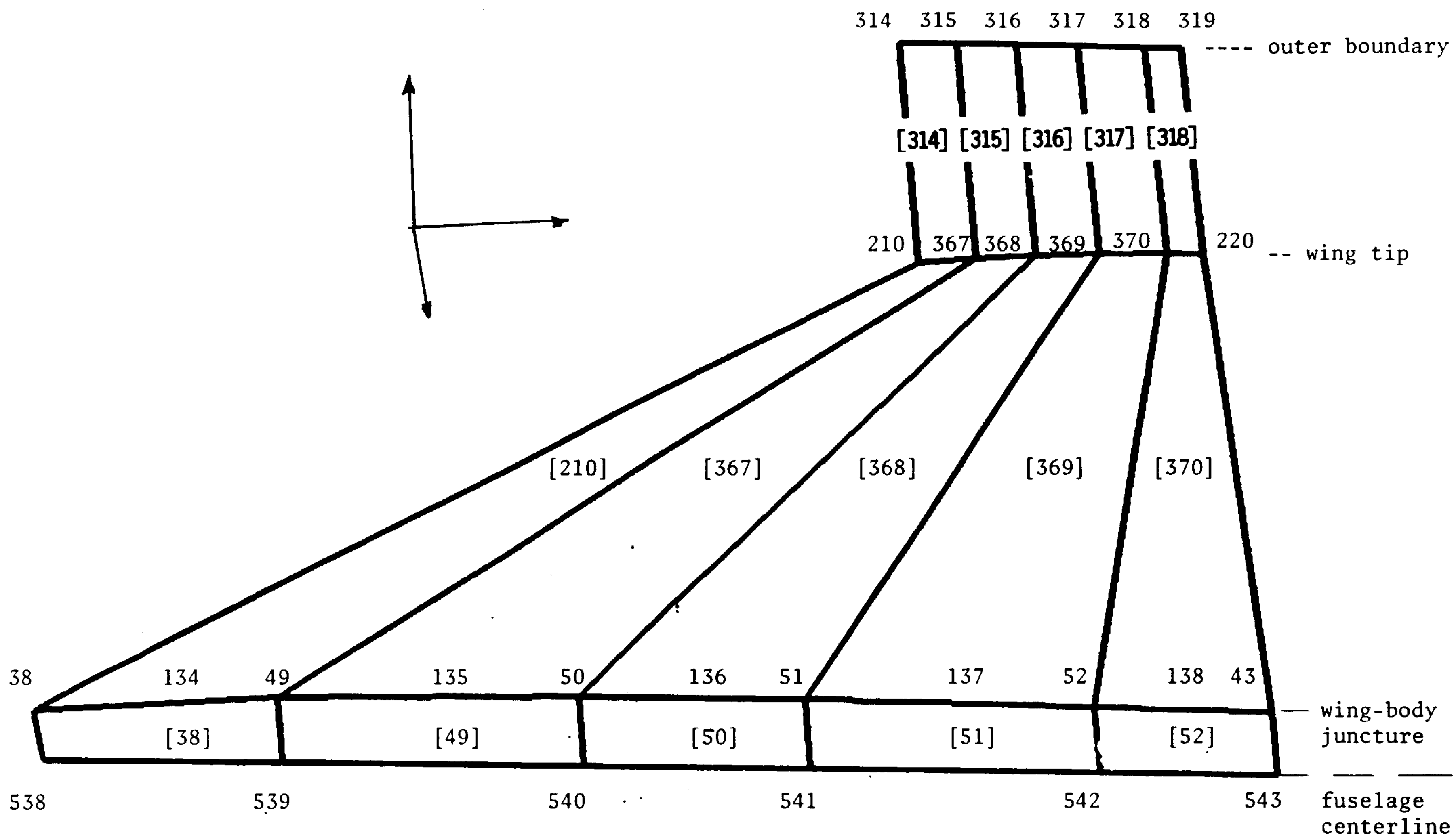


Figure 5.2 Wing-body surface (file gf.mac)

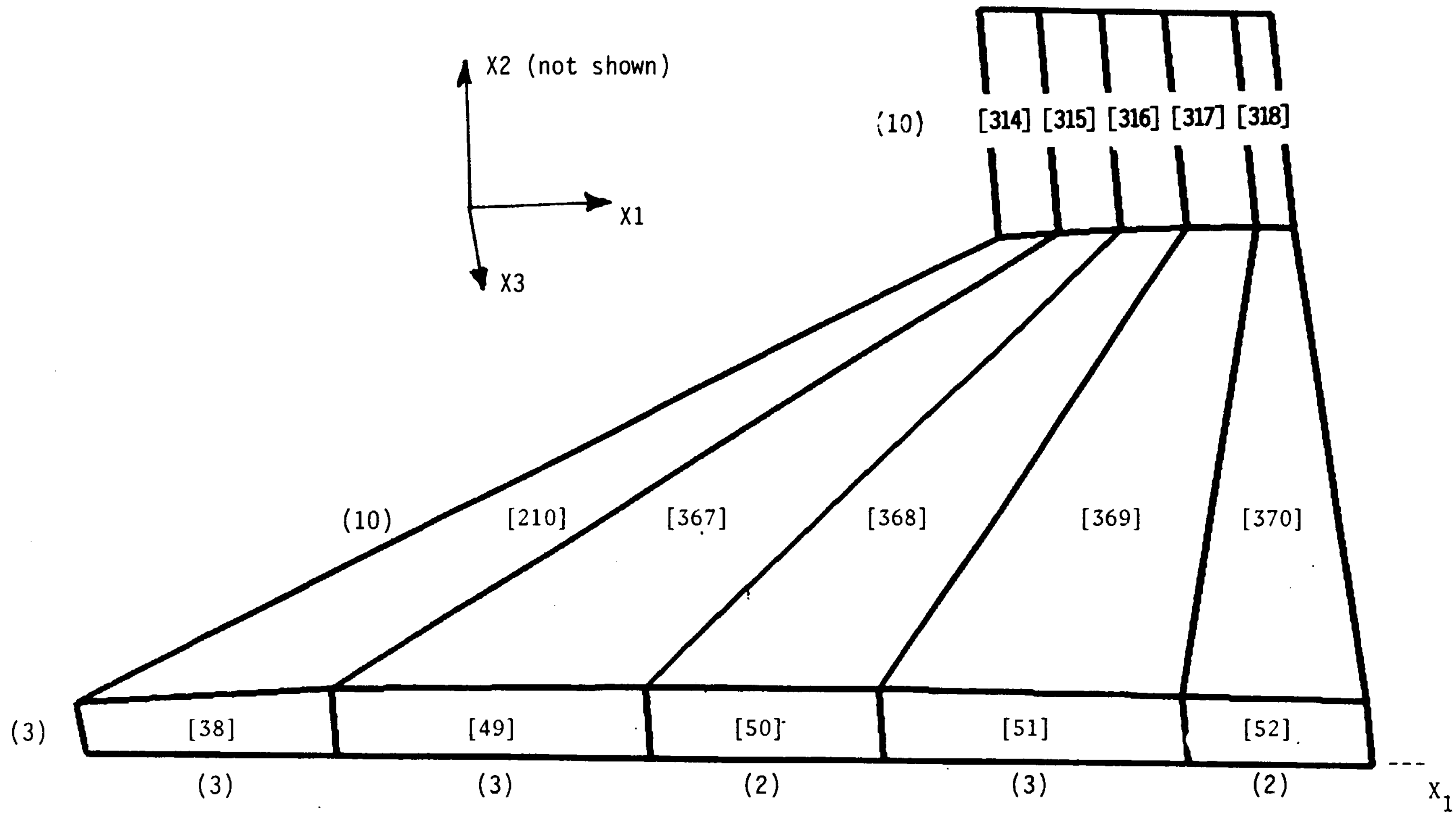


Figure 5.3 Finite element grid distribution (file gf.mac)

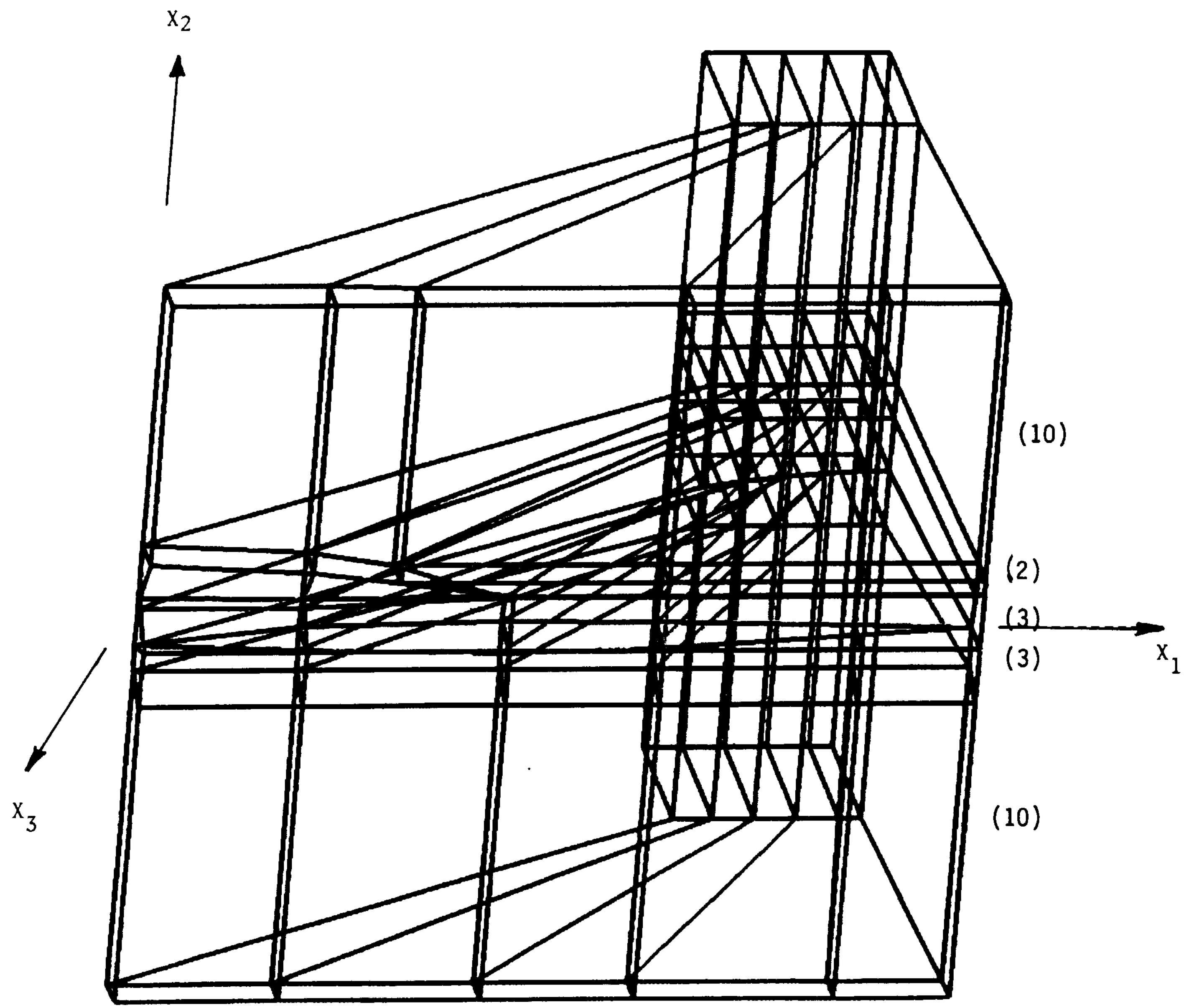


Figure 5.4 Three-dimensional macro element grid (stacked planes)

5.1 MACRO-ELEMENT DATA

The macro-element data is prepared from the sketches of macro-element planes described above. Macro-elements have 8 corner (vertex) gridpoints and 12 side gridpoints at which the data for quadratic interpolation of grid and initial values are specified. The numbering of each macro-element proceeds according to the convention illustrated in Figure 5.5. Note that each macro-element number corresponds to the first node on the macro-element.

A partial list of the macro-element data for the wing portion of the Generic fighter is illustrated in Figure 5.6. The first four lines contain titling and other parametric information. The variables pertinent to aerodynamic meshes are briefly described in Table 5.1. Data appearing in Figure 5.6a but not described in Table 5.1 should have the values shown in the Figure.

The rest of the macro-element data occurs in sets of three lines for each macro element. The first line (line 6 in Figure 5.6) contains the macro-element number (arbitrary), the number of macro-element corner points (vertices), the total number of macro-element gridpoints, the number of vertex nodes on each refined element and the number of generated elements in each spacial direction of the macro-element (from Figure 5.3 , 5.4); these are followed by the macro-element material (one or greater).

The second and third lines of each macro-element indicate the gridpoint numbers for the macro-element ordered according to Figure 5.5. These data are available from planes of macro grid prepared in advance (see Figure 5.2). All gridpoint numbers used must be listed in the macro-gridpoint section of the data directly following the macro-element data.

5.2 MACRO-GRIDPOINT DATA

The geometric coordinates of the macro-gridpoints are input according to the formats specified in Table 5.2. The first line for each gridpoint contains the macro gridpoint number, the grid attraction factor and local reference coordinate system for the point. The second line contains the coordinate system identifier (cartesian, cylindrical), the coordinates of the point and values of other distributed variables to be interpolated over a macro-element. NOTE that the number of variables being interpolated, including the coordinates, is specified as variable NC (see Table 5.1).

The input of macro-grid can be a time-consuming task and accurate specification of an aerodynamic surface requires the use of other programs more appropriate for this task. For example, for the generic fighter grids presented here, the macro gridpoints were interpolated from "pan-air" surface grid networks generated by NASA. Once the macro-grid is defined, however, a wide variety of grid refinements and attractions can be obtained through manipulation of the grid control parameters described above and in tables 5.1 and 5.2.

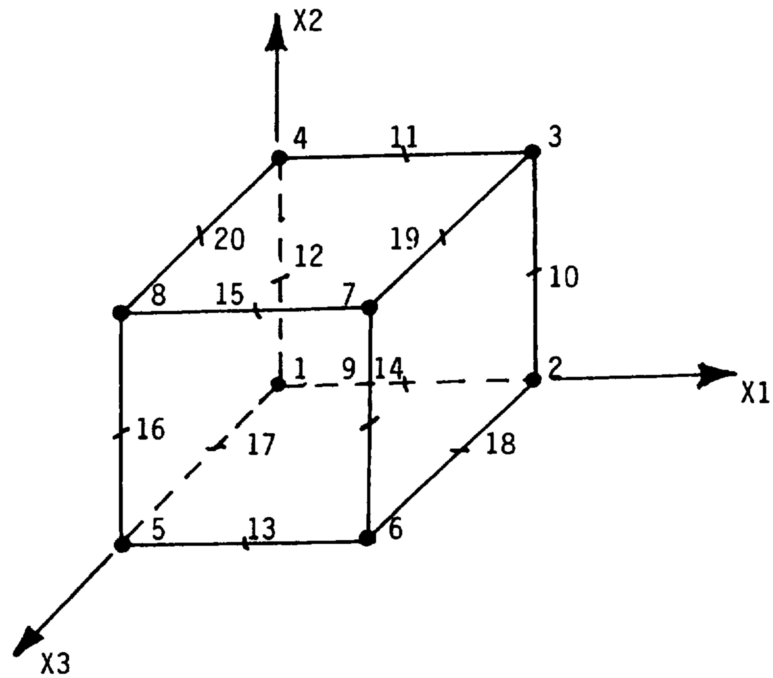


Figure 5.5a. Macro Element Gridpoint Numbering Convention

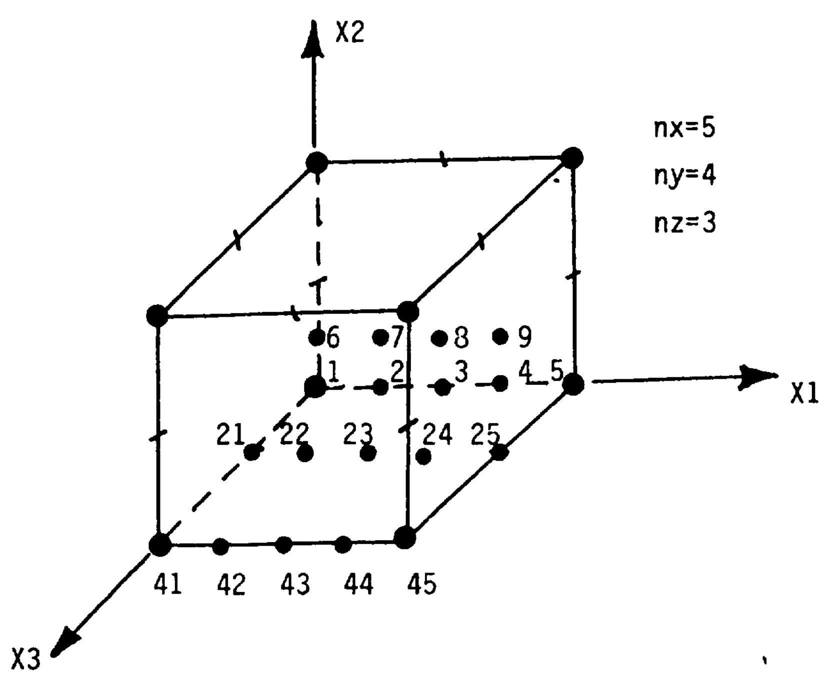


Figure 5.5b. Macro Element Generated Grid Order

```
  1     0     1     0     0     0     1
    3-d generic fighter short version (wing only)
586    30     3     1     0
  0
  0.00000E+00     0.00000E+00     0.00000E+00     1.00
299     8    20     8     1     1     1     0     1     0     0     0
      299   300   315   314   190   191   367   210     0     0     0     0     0     0   371
        0     0     0     0     0
300     8    20     8     1     1     1     0     1     0     0     0
      300   301   316   315   191   192   368   367     0     0     0     0     0     0   372
        0     0     0     0     0
301     8    20     8     1     1     1     0     1     0     0     0
      301   302   317   316   192   193   369   368     0     0     0     0     0     0   373
        0     0     0     0     0
302     8    20     8     1     1     1     0     1     0     0     0
      302   303   318   317   193   194   370   369     0     0     0     0     0     0   374
        0     0     0     0     0
303     8    20     8     1     1     1     0     1     0     0     0
      303   304   319   318   194   195   220   370     0     0     0     0     0     0   375
        0     0     0     0     0
314     8    20     8     1     1     1     0     1     0     0     0
      314   315   330   329   210   367   240   239     0     0     0     0   371     0     0
        0     0     0     0     0
315     8    20     8     1     1     1     0     1     0     0     0
      315   316   331   330   367   368   241   240     0     0     0     0   372     0     0
        0     0     0     0     0
316     8    20     8     1     1     1     0     1     0     0     0
      316   317   332   331   368   369   242   241     0     0     0     0   373     0     0
        0     0     0     0     0
317     8    20     8     1     1     1     0     1     0     0     0
      317   318   333   332   369   370   243   242     0     0     0     0   374     0     0
        0     0     0     0     0
318     8    20     8     1     1     1     0     1     0     0     0
      318   319   334   333   370   220   244   243     0     0     0     0   375     0     0
        0     0     0     0     0
190     8    20     8     1     1     1     0     1     0     0     0
      190   191   367   210   112   113    39    38     0     0   371     0   419   433   123
      432     0     0     0     0
191     8    20     8     1     1     1     0     1     0     0     0
      191   192   368   367   113   114    40    39     0     0   372     0   420   434   124
      433     0     0     0     0
192     8    20     8     1     1     1     0     1     0     0     0
      192   193   369   368   114   115    41    40     0     0   373     0   421   435   125
      434     0     0     0     0
193     8    20     8     1     1     1     0     1     0     0     0
      193   194   370   369   115   116    42    41     0     0   374     0   422   436   126
      435     0     0     0     0
194     8    20     8     1     1     1     0     1     0     0     0
      194   195   220   370   116   117    43    42     0     0   375     0   423   437   127
      436     0     0     0     0
210     8    20     8     1     1     1     0     1     0     0     0
      210   367   240   239    38    49   145   144   371     0     0     0   134   446   458
      445     0     0     0     0
367     8    20     8     1     1     1     0     1     0     0     0
      367   368   241   240    49    50   146   145   372     0     0     0   135   447   459
      446     0     0     0     0
368     8    20     8     1     1     1     0     1     0     0     0
      368   369   242   241    50    51   147   146   373     0     0     0   136   448   460
      447     0     0     0     0
```

Figure 5.6 Example macro element data (file gf.wing)

Table 5.1 MACRO-ELEMENT VARIABLES DESCRIPTION AND FORMATS

Figure 3.6	Name	Description	Format
LINE(1)	NTITLE	Number of title lines	(I5)
LINE(2)	TITLES	Alpha-Numeric title(s)	(80A1)
LINE(3)	NSNODE	Total No. macro gridpoints specified	(5I5)
	NSELEM	Total No. macro-elements specified	
	NC	No. variables to be refined (coordinates + others, X1,X2,X3	
	MLTOEL	No. variables having constant value over macro-element to be placed in generated element length arrays.	
	NTOEL	No. macro-gridpoint specified variables to be placed in generated element arrays.	
LINE(4)	JELVAR	Array of variable numbers which are macro gridpoint specified to be placed in generated element arrays (all other gridpoint data including coordinates are placed in generated node arrays).	(15I5)
LINE(6)	NZONE	Macro-element number	(15I5)
	ITYPE	No. macro-element vertices	
	JTYPE	No. macro-element gridpoints	
	IDLZ	No. generated vertices	
	NX	No. divisions in macro-element dir. (X1)	
	NY	No. divisions in macro-element dir. (X2)	
	NZ	No. divisions in macro-element dir. (X3)	
	MELEM	Indices constant over a macro-element which are placed in generated element length arrays (eg: material number).	
LINE(7)	ICODE	Grid Pt. Nos. defining Ea. macro-element Order determines local coordinate system side-ordering. e.g., the first macro-element in Fig.3.2 should be numbered 1,2,7,6, 26, 0, 30, 0, since the generated grid numbering is to be sequential in the first PNS plane (ie: over macro-nodes 1-5). All other macro-	(15I5)

Table 5.2 MACRO-GRIDPOINT VARIABLES DESCRIPTION AND FORMAT

Figure 3.6b	Name	Description	Format
LINE(1)	SNODE	Macro gridpoint number	(I5)
	SPREDS	Grid attraction factor The numbers 0-1.0 indicate coarse to fine grid generation in the immediate vicinity of a macro gridpoint.	
		ICOORD Global reference coordinates	(4E15.5)
LINE(2)	JCOORD	Input coordinate 0, cartesian (X,Y,Z) 1, cylindrical (r,θ,Z) system	
	SGRID	Contains the macro gridpoint coordinate data in first two locations. These are followed by other parameter data to be distributed over the solution domain. Parameter data consists (generally) of initial conditions, boundary conditions and distributed coefficients of the differential equation terms.	(I5,5e15.5)

Table 5.3 MACRO-ELEMENT STACKING DATA

The final step for geometry input is to order the macro-elements for lexico-graphic numbering. Referring to Figure 3.2, the macro-element numbering sequence which provides output in plane normal to the X_1 axes is as shown in the Figure. The format for inputting the stacking data is as follows:

	Name	Description	Format
LINE(1)		No. of columns No. of planes	2I5
LINE(2)		No. of macro-elements this line Macro-element numbers	15I5

```
       1      0.00
             -5.0          -11.8365        0.0
       2      0.00
              1.2          -11.8365        0.0
       3      0.00
              3.86332      -11.8365        0.0
       4      0.00
              6.78634      -11.8365        0.0
       5      0.00
             11.0          -11.8365        0.0
       6      0.00
             12.75         -11.8365        0.0
       7      0.00
             16.0          -11.8365        0.0
       8      0.00
             16.13453      -11.8365        0.0
       9      0.00
             20.2021       -11.8365        0.0
      10      0.00
             25.25         -11.8365        0.0
      11      0.00
             29.05481      -11.8365        0.0
      12      0.00
             33.98665      -11.8365        0.0
      13      0.00
             36.88745      -11.8365        0.0
      14      0.00
             42.0          -11.8365        0.0
      15      0.00
             47.0          -11.8365        0.0
      16      0.00
             -5.0          -0.48034        0.0
      17      0.00
              1.2          -0.48034        0.0
      18      0.00
              3.86332      -1.2113         0.0
      19      0.00
              6.78634      -1.61918        0.0
      20      0.00
             11.0          -1.81817        0.0
      21      0.00
             12.75         -1.83650        0.0
      22      0.00
             16.0          -1.83650        0.0
      23      0.00
             16.13453      -1.83650        0.0
       0
   6   4   4   0   1   1   0   0   0   0   0   0   0   0   0
   3   2
   5   1   2   3   4   5
   5   6   7   8   9  10
   5  11  12  13  14  15
   5  16  17  18  19  20
   5  21  22  23  24  25
   5  26  27  28  29  30
X1
X2
X3
```

Figure 5.7 Example macro gridpoint and macro element stacking data (file gf.wing).

5.3 MACRO-ELEMENT STACKING DATA

The order of macro-element input is arbitrary to allow for easy addition or deletion of macro-elements without any repositioning. For finite element codes which run on unstructured grids, no other input is required since the generated elements can be in arbitrary order. For structured grid codes, however, the macro-elements need to be aligned in a way that permits lexico-graphic ordering of the generated finite elements and nodal arrays.

The macro-element stacking data organizes the macro-elements into columns, rows and planes of adjacent blocks as illustrated in Figure 5.8. The generated grid for each macro-element (Figure 5.5b) is automatically renumbered to account for adjacent macro-elements. The result is a final grid ordering which begins at the origin; increments in each row in the X-direction, proceeding in the y-direction in Figure 5.8 to complete a plane and finally in the Z-direction, completing all planes. NOTE that in order for all generated finite elements to be of the same polynomial degree, the number of subdivisions in adjacent macro-elements must be equal.

Specification of the macro-element stacking data is illustrated at the end of Figure 5.7 and specific formats are in Table 5.3.

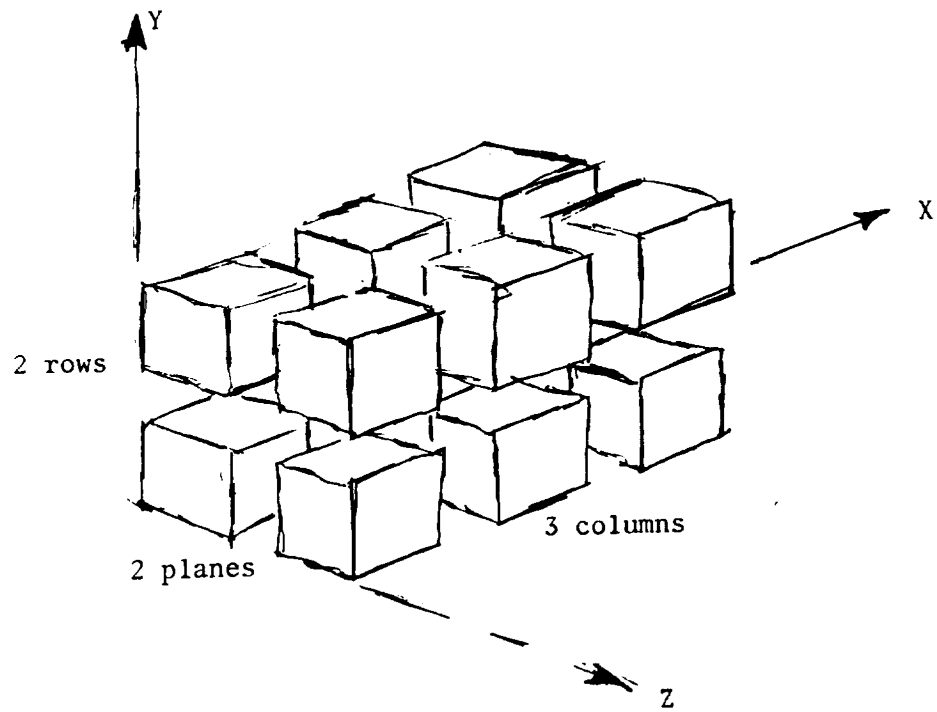


Figure 5.8 Macro element stacking data

APPENDIX

BOUNDARY CONDITION DATA

For

FEMNAS

SFILL2 Module Dialogue

For

Axisymmetric Blunt Body

```
DO YOU WISH TO SET-UP BOUNDARY-CONDITION INFORMATION ?
1<< YES
2<<  NO
          1

 BOUNDARY CONDITIONS

HOW MANY BOUNDARY SECTIONS ? (<=20)
          8
          8  SECTIONS
NOW ENTER:  1 ,TO CONFIRM
          1
 THE BOUNDARY SECTION INFORMATION IS
 REQUIRED IN A COUNTER CLOCK WISE ORDER

SECTION              1
 TYPE OF BOUNDARY ?
1<< INFLOW   BOUNDARY
2<< INFLOW   BOUNDARY CORNER
3<< OUTFLOW BOUNDARY CORNER
4<< OUTFLOW BOUNDARY
5<< WALL     BOUNDARY
          2
THE TYPE SELECTED IS           2
NOW ENTER:  1 ,TO CONFIRM
          1

SECTION              1
 TYPE OF PRESCRIBED BC ?
1<<    d(Qi)/dn=0
2<<    RO
3<<    MX
4<<    MY
5<<    RO   & MX
```

```
6<<    RO   & MY & E
7<<    MX   & MY
8<<    RO   & MX & MY & E
          8
THE TYPE SELECTED IS          8
NOW ENTER:  1 ,TO CONFIRM
          1

FIRST
EXTREME NODE OF SECTION             1
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
          1
ELEMENT COLUMN ?
          1
NODE LOCAL NUMBER ?
          1
ELEMENT           1  NODE             1
NODE LOCAL NUMBER:            1
ROW            1  COLUMN            1
NOW ENTER:  1 ,TO CONFIRM
          1


SECOND
EXTREME NODE OF SECTION             1
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
          1
ELEMENT COLUMN ?
          1
NODE LOCAL NUMBER ?
          1
ELEMENT           1  NODE             1
NODE LOCAL NUMBER:            1
ROW            1  COLUMN            1
NOW ENTER:  1 ,TO CONFIRM
          1


SECTION             2
 TYPE OF BOUNDARY ?
1<< INFLOW  BOUNDARY
2<< INFLOW  BOUNDARY CORNER
3<< OUTFLOW BOUNDARY CORNER
4<< OUTFLOW BOUNDARY
5<< WALL    BOUNDARY
          1
THE TYPE SELECTED IS          1
NOW ENTER:  1 ,TO CONFIRM
          1

SECTION             2
 TYPE OF PRESCRIBED BC ?
1<<    d(Qi)/dn=0
2<<    RO
3<<    MX
4<<    MY
5<<    RO   & MX
6<<    RO   & MY & E
7<<    MX   & MY
8<<    RO   & MX & MY & E
          4
THE TYPE SELECTED IS          4
```

```
NOW ENTER:  1 ,TO CONFIRM
          1

FIRST
EXTREME NODE OF SECTION            2
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
          1
ELEMENT COLUMN ?
          1
NODE LOCAL NUMBER ?
          2
ELEMENT            1  NODE           52
NODE LOCAL NUMBER:           2
ROW           1  COLUMN            1
NOW ENTER:  1 ,TO CONFIRM
          1


SECOND
EXTREME NODE OF SECTION            2
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
          1
ELEMENT COLUMN ?
         50
NODE LOCAL NUMBER ?
          1
ELEMENT         2451  NODE         2500
NODE LOCAL NUMBER:           1
ROW           1  COLUMN           50
NOW ENTER:  1 ,TO CONFIRM
          1


SECTION            3
 TYPE OF BOUNDARY ?
1<< INFLOW  BOUNDARY
2<< INFLOW  BOUNDARY CORNER
3<< OUTFLOW BOUNDARY CORNER
4<< OUTFLOW BOUNDARY
5<< WALL    BOUNDARY
          1
THE TYPE SELECTED IS           1
NOW ENTER:  1 ,TO CONFIRM
          1

SECTION            3
 TYPE OF PRESCRIBED BC ?
1<<   d(Qi)/dn=0
2<<   RO
3<<   MX
4<<   MY
5<<   RO  & MX
6<<   RO  & MY & E
7<<   MX  & MY
8<<   RO  & MX & MY & E
          7
THE TYPE SELECTED IS           7
NOW ENTER:  1 ,TO CONFIRM
          1

FIRST
EXTREME NODE OF SECTION            3
```

```
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
          1
ELEMENT COLUMN ?
         50
NODE LOCAL NUMBER ?
          2
ELEMENT        2451  NODE        2551
NODE LOCAL NUMBER:           2
ROW             1  COLUMN        50
NOW ENTER:  1 ,TO CONFIRM
          1


SECOND
EXTREME NODE OF SECTION           3
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
          1
ELEMENT COLUMN ?
         50
NODE LOCAL NUMBER ?
          2
ELEMENT        2451  NODE        2551
NODE LOCAL NUMBER:           2
ROW             1  COLUMN        50
NOW ENTER:  1 ,TO CONFIRM
          1


SECTION              4
 TYPE OF BOUNDARY ?
1<< INFLOW  BOUNDARY
2<< INFLOW  BOUNDARY CORNER
3<< OUTFLOW BOUNDARY CORNER
4<< OUTFLOW BOUNDARY
5<< WALL    BOUNDARY
          1
THE TYPE SELECTED IS           1
NOW ENTER:  1 ,TO CONFIRM
          1

SECTION              4
 TYPE OF PRESCRIBED BC ?
1<<   d(Qi)/dn=0
2<<   RO
3<<   MX
4<<   MY
5<<   RO  & MX
6<<   RO  & MY & E
7<<   MX  & MY
8<<   RO  & MX & MY & E
          7
THE TYPE SELECTED IS           7
NOW ENTER:  1 ,TO CONFIRM
          1

FIRST
EXTREME NODE OF SECTION           4
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
          1
ELEMENT COLUMN ?
```

```
         50
NODE LOCAL NUMBER ?
          3
ELEMENT          2451  NODE         2552
NODE LOCAL NUMBER:               3
ROW             1  COLUMN         50
NOW ENTER:  1 ,TO CONFIRM
          1


SECONDEXTREME NODE OF SECTION            4
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
         50
ELEMENT COLUMN ?
         50
NODE LOCAL NUMBER ?
          2
ELEMENT          2500  NODE         2600
NODE LOCAL NUMBER:               2
ROW            50  COLUMN         50
NOW ENTER:  1 ,TO CONFIRM
          1


SECTION              5
 TYPE OF BOUNDARY ?
1<< INFLOW  BOUNDARY
2<< INFLOW  BOUNDARY CORNER
3<< OUTFLOW BOUNDARY CORNER
4<< OUTFLOW BOUNDARY
5<< WALL    BOUNDARY
          1
THE TYPE SELECTED IS           1
NOW ENTER:  1 ,TO CONFIRM
          1

SECTION              5
 TYPE OF PRESCRIBED BC ?
1<<   d(Qi)/dn=0
2<<   RO
3<<   MX
4<<   MY
5<<   RO  & MX
6<<   RO  & MY & E
7<<   MX  & MY
8<<   RO  & MX & MY & E
          7
THE TYPE SELECTED IS           7
NOW ENTER:  1 ,TO CONFIRM
          1

FIRST
EXTREME NODE OF SECTION            5
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
         50
ELEMENT COLUMN ?
         50
NODE LOCAL NUMBER ?
          3
ELEMENT          2500  NODE         2601
NODE LOCAL NUMBER:               3
```

```
ROW            50  COLUMN           50
NOW ENTER:  1 ,TO CONFIRM
          1


SECOND
EXTREME NODE OF SECTION             5
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
         50
ELEMENT COLUMN ?
         50
NODE LOCAL NUMBER ?
          3
ELEMENT          2500  NODE         2601
NODE LOCAL NUMBER:               3
ROW            50  COLUMN           50
NOW ENTER:  1 ,TO CONFIRM
          1


SECTION              6
 TYPE OF BOUNDARY ?
1<< INFLOW  BOUNDARY
2<< INFLOW  BOUNDARY CORNER
3<< OUTFLOW BOUNDARY CORNER
4<< OUTFLOW BOUNDARY
5<< WALL    BOUNDARY
          1
THE TYPE SELECTED IS              1
NOW ENTER:  1 ,TO CONFIRM
          1

SECTION              6
 TYPE OF PRESCRIBED BC ?
1<<   d(Qi)/dn=0
2<<   RO
3<<   MX
4<<   MY
5<<   RO  & MX
6<<   RO  & MY & E
7<<   MX  & MY
8<<   RO  & MX & MY & E
          1
THE TYPE SELECTED IS              1
NOW ENTER:  1 ,TO CONFIRM
          1

FIRST
EXTREME NODE OF SECTION             6
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
         50
ELEMENT COLUMN ?
         50
NODE LOCAL NUMBER ?
          4
ELEMENT          2500  NODE         2550
NODE LOCAL NUMBER:               4
ROW            50  COLUMN           50
NOW ENTER:  1 ,TO CONFIRM
          1
```

```
SECOND
EXTREME NODE OF SECTION            6
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
         50
ELEMENT COLUMN ?
          1
NODE LOCAL NUMBER ?
          3
ELEMENT            50  NODE         102
NODE LOCAL NUMBER:           3
ROW            50  COLUMN           1
NOW ENTER:  1 ,TO CONFIRM
          1


SECTION              7
 TYPE OF BOUNDARY ?
1<< INFLOW  BOUNDARY
2<< INFLOW  BOUNDARY CORNER
3<< OUTFLOW BOUNDARY CORNER
4<< OUTFLOW BOUNDARY
5<< WALL    BOUNDARY
          1
THE TYPE SELECTED IS           1
NOW ENTER:  1 ,TO CONFIRM
          1

SECTION              7
 TYPE OF PRESCRIBED BC ?
1<<   d(Qi)/dn=0
2<<   RO
3<<   MX
4<<   MY
5<<   RO  & MX
6<<   RO  & MY & E
7<<   MX  & MY
8<<   RO  & MX & MY & E
          7
THE TYPE SELECTED IS           7
NOW ENTER:  1 ,TO CONFIRM
          1

FIRST
EXTREME NODE OF SECTION            7
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
         50
ELEMENT COLUMN ?
          1
NODE LOCAL NUMBER ?
          4
ELEMENT            50  NODE          51
NODE LOCAL NUMBER:           4
ROW            50  COLUMN           1
NOW ENTER:  1 ,TO CONFIRM
          1


SECOND
EXTREME NODE OF SECTION            7
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
```

```
          50
ELEMENT COLUMN ?
           1
NODE LOCAL NUMBER ?
           4
ELEMENT          50  NODE          51
NODE LOCAL NUMBER:            4
ROW          50  COLUMN           1
NOW ENTER:  1 ,TO CONFIRM
           1


SECTION            8
 TYPE OF BOUNDARY ?
1<< INFLOW  BOUNDARY
2<< INFLOW  BOUNDARY CORNER
3<< OUTFLOW BOUNDARY CORNER
4<< OUTFLOW BOUNDARY
5<< WALL    BOUNDARY
           1
THE TYPE SELECTED IS            1
NOW ENTER:  1 ,TO CONFIRM
           1

SECTION            8
 TYPE OF PRESCRIBED BC ?
1<<   d(Qi)/dn=0
2<<   RO
3<<   MX
4<<   MY
5<<   RO  & MX
6<<   RO  & MY & E
7<<   MX  & MY
8<<   RO  & MX & MY & E
           8
THE TYPE SELECTED IS            8
NOW ENTER:  1 ,TO CONFIRM
           1

FIRST
EXTREME NODE OF SECTION           8
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
          50
ELEMENT COLUMN ?
           1
NODE LOCAL NUMBER ?
           1
ELEMENT          50  NODE          50
NODE LOCAL NUMBER:            1
ROW          50  COLUMN           1
NOW ENTER:  1 ,TO CONFIRM
           1


SECOND
EXTREME NODE OF SECTION           8
NODE LOCATION
ELEMENT CO-ORDINATES
ELEMENT ROW ?
           1
ELEMENT COLUMN ?
           1
NODE LOCAL NUMBER ?
           4
```

```
 ELEMENT              1  NODE            2
 NODE LOCAL NUMBER:            4
 ROW           1  COLUMN            1
 NOW ENTER:  1 ,TO CONFIRM
          1

 THE BOUNDARY-CONDITION CODE FILE HAS BEEN
 CREATED
STOP sfill complete
```